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AD-A215 696

Soviet Advanced Technologies in the Era of Restructuring

Simon Kassel

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DISTRIBUTION STATEMENT A

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The research described in this report was sponsored by the Defense Advanced Research Projects Agency under RAND's National Defense Research Institute, a Federally Funded Research and Development Center supported by the Office of the Secretary of Defense, Contract No. MDA903-85-C-0030; and by The RAND Corporation using its own research funds.

Library of Congress Cataloging in Publication Data

Kassel, Simon.

Soviet advanced technologies in the era of restructuring.

"Prepared for the Defense Advanced Research Projects Agency."

"April 1989."

"R-3653-DARPA/RC."

Bibliography: p.

1. High technology—Soviet Union. I. RAND Corporation.

II. United States. Defense Advanced Research Projects Agency.

III. Title.

T26.S65K37 1989 338.9'27'0947 89-8411

ISBN 0-8330-0954-0

The RAND Publication Series: The Report is the principal publication documenting and transmitting RAND's major research findings and final research results. The RAND Note reports other outputs of sponsored research for general distribution. Publications of The RAND Corporation do not necessarily reflect the opinions or policies of the sponsors of RAND research.

Published by The RAND Corporation
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90406-2138

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-3653-DARPA/RC	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Soviet Advanced Technologies in the Era of Restructuring		5. TYPE OF REPORT & PERIOD COVERED interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Simon Kassel		8. CONTRACT OR GRANT NUMBER(s) MDA903-85-C-0030
9. PERFORMING ORGANIZATION NAME AND ADDRESS The RAND Corporation 1700 Main Street Santa Monica, CA 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209		12. REPORT DATE April 1989
		13. NUMBER OF PAGES 105
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) unclassified
		16. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of this Report) Approved for Public Release; Distribution Unlimited		
18. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) No Restrictions		
19. SUPPLEMENTARY NOTES		
20. KEY WORDS (Continue on reverse side if necessary and identify by block number) USSR Foreign Technology		
21. ABSTRACT (Continue on reverse side if necessary and identify by block number) see reverse side		

DD FORM 1 JAN 73 1473

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

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This report assesses the capability and prospects for Soviet development of advanced technologies within the framework of the restructuring drive currently under way in the Soviet Union. The author analyzes recent Soviet technical literature, providing an overview of the restructuring process, its objectives for advanced technology development, the pace and extent of their realization, and the fundamental problems involved in the transition from leading-edge research and development (R&D) to industrial production. He suggests that Soviet problems with R&D arise largely from the revolutionary nature of advanced technology, the successful development of which requires an economic and industrial environment that is incompatible with rigidly applied principles of planned economy. The Soviet systemic aversion to risk and uncertainty has the greatest negative influence on the development of advanced technologies. Because Soviet failure to keep pace with the West in technological development is ultimately political in origin, it cannot be reversed without profound political changes of the system.

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

R-3653-DARPA/RC

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PREFACE

This report assesses the capability and prospects of Soviet development of advanced technologies within the framework of the restructuring drive currently under way in the USSR. The work was sponsored by the Defense Advanced Research Projects Agency, Office of the Secretary of Defense (OSD), and was carried out in the Applied Science and Technology Program of the National Defense Research Institute, RAND's OSD-supported Federally Funded Research and Development Center. Supplemental support for the completion of this report was provided by The RAND Corporation through the use of its discretionary funds.

The report analyzes recent Soviet technical literature, providing an overview of the restructuring process, its objectives for advanced technology development, the pace and extent of their realization, and the fundamental problems involved in the transition from leading-edge R&D to industrial production. As an end result of a series of studies evaluating the progress of Soviet R&D reforms, the report also incorporates material from two previously published RAND Notes by this author. The first, *A New Force in the Soviet Computer Industry: The Reorganization of the USSR Academy of Sciences in the Computer Field*, N-2486-ARPA, provides an account of the effort to accelerate the development of Soviet computer technology, the most important and the most deficient of Soviet advanced technologies. The second, *Soviet High-Technology Restructuring Drive: The MNTK Network*, N-2612-DARPA, extends the coverage of Soviet industrial reform activities to the range of technologies developed by the recently established network of interbranch science and technology complexes.

The report should be of interest to U.S. decisionmakers involved in assessing Soviet technological and industrial posture, students of Soviet science and technology, and analysts interested in the process of interaction between R&D and industrial production.



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Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

10001

SUMMARY

The present report deals with the question: Can the USSR close the advanced technology gap as a result of the current restructuring drive? In the second year of restructuring, the answers are not encouraging. The development of advanced technologies is an extraordinary challenge to the Soviet economic system, demanding radical departures from the way in which the Soviets have been accustomed to proceed with industrialization and the more traditional technologies. But the spirit, if not the letter, of restructuring has, so far at least, appeared not radical enough to meet that challenge.

The deepest and most damaging cause of Soviet problems with industrial innovation and an impoverished technology base is the essential incompatibility between rigid economic planning and risk-taking independent entrepreneurship that drives the development of new technologies. The latter operates not according to preconceived plans, but according to the developer's perception of what is feasible and marketable. Although the institution of effective economic incentives to innovation and the elimination of bureaucratic barriers between R&D and production are at least conceivable within the Soviet system, the introduction of a broad stratum of independent entrepreneurs is impossible without a profound political alteration of that system.

Soviet restructuring policy recognizes the significance of independence and risk-taking in technological development: the September 1987 decision of the Central Committee and the Council of Ministers to place R&D organizations on a self-supporting and self-financing basis casts at least some research institutes in the role of relatively independent developers of technology. Under liberalized rules governing the distribution of profit-derived revenues, these institutes may be able to launch the development of new technologies because of their inherent potential, rather than in response to state direction. But the question remains if the economic reforms go far enough in liberalizing industrial production from state plans to create industrial sponsors willing and able to pay for such development.

The primary document of restructuring, the March 1986 resolution of the 27th Party Congress, calls in general terms for the development of electronics, atomic energy, systems automation, and the technology of production and treatment of new materials. But it does not specify how these technologies are to be developed and, what is most important, does not elevate such advanced technologies as microprocessors,

systems automation, composite materials, and the like to the rank of distinct industries in their own right; instead, it deals with them mainly in the context of the more traditional industries, such as machine tools or electric power. There is no mention of advanced radio, television, electron-optics, or telecommunications technologies.

Thus, restructuring, in the light of the resolution of the Party Congress, appears more concerned with upgrading traditional industries than with establishing new industries based on advanced technologies.

The reform includes the Academy of Sciences and its institutes among the new organizations designed to integrate R&D and production. Under restructuring, the Academy is perceived as more active in matters directly pertinent to industrial innovation, but less autonomous than before and more dependent on the state in choosing the scope and subject of its activity. In particular, the Academy will be supervised to some extent by the State Committee for Science and Technology, which "determines priority R&D areas" and "manages major scientific projects."

The Academy of Sciences launched the earliest of the current technological reforms to deal specifically with advanced technologies. The development of Soviet computer technology has been spearheaded by Ye. P. Velikhov, Vice-President of the Academy of Sciences and long-time supporter of pulsed-power, fusion, and directed energy development in the USSR. The timing of the event and Velikhov's background strongly suggest space defense as a primary objective. Velikhov stated that the goal was to secure a native scientific and technological base "capable of eliminating the national computer deficiency in the shortest possible time."

Another major venture of restructuring has been the establishment of a network of large organizations bridging the gap between R&D and production. These interbranch science and technology complexes, are known as MNTKs and represent the latest and strongest attempt to overcome the chronic Soviet lag in advanced technologies. The MNTKs are impressive in the speed of their introduction, their size, and the unprecedented nature of their charter, but not, however, in their operating effectiveness.

One-and-a-half years after the enabling legislation, there are 23 MNTKs, some of which incorporate dozens of scientific research institutes together with large industrial production enterprises and several science-production associations. For the first time, an effort has been made to engage the institutes of the Academy of Sciences on a massive scale in the industrial innovation process.

The economic aspect of restructuring is based on the principle of profit as "the only valid criterion of enterprise activity, the real source

of the life of the collective, and the indicator of its work." The targets of reform also include decentralization and local autonomy of planning and management, realistic pricing policy, and economic incentives for work.

But the profits earned by R&D organizations that belong to production associations and enterprises will be included in the total profit of the associations, treating the support of R&D as part of the cost of production. Since the new rules insist on concentrating industrial R&D organizations in the production associations and enterprises, the limitations on profit control will diminish the promise of independence of R&D inherent in the transition to the self-supporting mode.

Restructuring faces resistance from vested interests of Soviet bureaucracy based on the old economic order and manifested in the breach between the top-level restructuring policy and the management of the national economy. The latter continues to be based on quantitative cost indicators of production growth and does not take into account the quality of production, efficiency of resource use, and the effect of prices. Its technological conservatism is also evident in the profiles of the MNTKs, more of which are oriented toward materials and process improvement in the metallurgical, machine-building, chemical, and oil extraction industries, than toward advanced technologies dominant in the West, such as electronics, computers, plastics, and composites.

The MNTKs also clearly illustrate the effect of bureaucratic resistance to restructuring and the cleavage between the government's plans and decrees, and their realization in practice. In contrast to the speed of their formal establishment, further steps toward practical implementation of the MNTKs have been quite slow. The resistance has been eroding the effectiveness of the new organizations, particularly the power to enforce their new rights and privileges. As a result, Soviet observers question the potential of the MNTKs, and some critics already call them paper tigers.

However, the breach between intentions and actual implementation of the new policy is not wholly due to obstructionism. To a large extent, it has also been due to the persistence of the regulatory mechanism which controls all economic transactions in the USSR and which requires extensive and laborious amendments at all administrative levels in order to make the new policies work.

The new restructuring measures are neither well established nor understood by the rank and file. Confusion is further compounded by the absence of an economic theory of restructuring, which may prove to be profoundly disconcerting to people conditioned by permanent obeisance to ideology. At this time, the practical implementation of

restructuring appears to be focused mainly on labor relations, where it is intent on strengthening work discipline and efficiency. Indeed, labor may well prove to be the most troublesome source of opposition to the new economic reform.

Nevertheless, it is imperative for the Soviets to make restructuring work both to bolster the economy's capability to respond to the growing societal requirements and to secure military capability to compete in terms of advanced technologies. Their success depends on how far they are prepared to go in changing the Soviet economic system. The official decrees promulgating the reform measures so far give the impression of chaotic, hastily drawn documents. It remains to be seen whether this urgency to install restructuring in Soviet society as soon as possible will be later replaced by a more thoughtful approach to the problems of Soviet R&D and industry.

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ACRONYMS

FIAN	<i>Fizicheskiy institut Akademii Nauk</i> (Physics Institute of the Academy of Sciences)
FTI	<i>Fiziko-tekhnicheskiy institut</i> (Physico-technical Institute)
GKNT	<i>Gosudarstvennyy komitet po nauke i tekhnike</i> (State Committee for Science and Technology)
IRE	<i>Institut radiotekhniki i elektroniki</i> (Institute of Radio-engineering and Electronics)
KTU	<i>Koeffitsient trudovogo uchastiya</i> (Labor participation coefficient)
LSI	Large system integration
MHD	Magnetohydrodynamic
<i>Minelektronprom</i>	Ministry of Electronics Industry
<i>Minelektrotekhprom</i>	Ministry of Electro-technical Industry
<i>Minpribor</i>	Ministry of Instrument Construction, Automation Equipment, and Control Systems
<i>Minradioprom</i>	Ministry of Radio Industry
MNTK	<i>Mezhotraslevyy nauchno-tekhnicheskiy kompleks</i> (Interbranch Science and Technology Complex)
NITsTLAN	<i>Nauchno-issledovatel'skiy tsentr tekhnicheskikh lazerov Akademii Nauk</i> (Scientific Research Center for Industrial Lasers of the Academy of Sciences)
NPO	<i>Nauchno-proizvodstvennoye ob'yedineniye</i> (Science-Production Association)
NTK	<i>Nauchno-tekhnicheskiy kompleks</i> (Science and Technology Complex)
VAN SSSR	<i>Vestnik Akademii Nauk, SSSR</i> (Herald of the Academy of Sciences, USSR)
VLSI	Very large system integration

VNPO	<i>Vsesoyuznoye nauchno-proizvodstvennoye ob'yedineniye</i> (All-Union Science-Production Association)
VTsSPS	<i>Vsesoyuznyy tsentral'nyy sovyet profsoyuzov</i> (All-Union Central Council of Trade Unions)
VUZ	<i>Vysshiye uchebnyye zavedeniya</i> (Higher education schools; universities)

I. INTRODUCTION

Steel provides a good paradigm of the state of Soviet technology: the USSR is the largest producer of steel in the world, with an annual production rate double that of the United States. But steel is an obsolete material in some applications, having been replaced by aluminum, plastics, and composites. The increasing use of these other materials has contributed to the declining production growth rate of steel in the United States. This has not occurred in the Soviet Union, whose industry has, so far, failed to master, absorb, and disseminate the requisite advanced materials technologies in a degree sufficient to offset the need for steel.¹ The failure to modernize extends to other advanced technologies as well, among which the lag in computer technology has been the most prominent.

The purpose of this report is to consider the question: What has the current restructuring drive been doing to recover from this failure and to promote the development of advanced technologies, as distinct from its general efforts to improve current industrial performance?

The distinction is important because advanced technologies, otherwise known as high or exotic technologies, are the new products of R&D that in many ways are radically different from older technologies that have already been assimilated more or less successfully by Soviet industry. One basic distinction of advanced technologies is their need for highly intensive and risky R&D which must be supported by equally advanced experimental research facilities, effective interaction between science and industry, broadly interdisciplinary approach to research, a broad technology base capable of supplying component technologies, and uninhibited flow of information with access to computers and data banks. What is most important, the developers of advanced technologies must have funding to pursue research objectives that are free of the rigid commitments implicit in state plans.

¹A recent Soviet example cites the case of the pipe industry. The Soviet Union now consumes a quantity of steel pipes equal to that consumed by the United States, Japan, West Germany, Britain, France, and Italy combined. In those countries the consumption of steel pipes is steadily declining, and they are used only where they cannot be replaced by nonmetallic pipes. The Soviet need for such pipes is particularly aggravated in gas transportation, water supply, and irrigation. Plastic pipes should save a large quantity of metal, since one metric ton of plastic pipe replaces four to five tons of steel pipe. However, the plan specifies a plastic pipe production level for 1990 that is five times lower than that reached by the United States in 1984. The reason given is lack of polyethylene and of production capacities.[1]

Many, if not all, of these requirements are difficult to meet under Soviet conditions and call for the introduction of qualitatively new economic, social, and organizational approaches to the problem. But the past Soviet leadership was unwilling to attempt radical change and allowed the lag in advanced technologies to continue increasing. Although the USSR is a leading industrial power, this position has been attained largely in terms of traditional technologies. The long-standing Soviet dedication to forced industrialization has neglected many of the prerequisites for advanced technology development, and even opposed others, such as the unhindered capability to innovate which has often been perceived as interfering with traditional goals of maximizing industrial production.

For the past several years, the state of Soviet advanced technologies has been a matter of steadily mounting concern for the Soviet leadership. One reason has been the increasing importance of advanced technologies to the military industry. Another has been the prospect of space technology competition with the United States, triggered by the Strategic Defense Initiative, to be pursued almost exclusively with advanced technologies. But perhaps the most important reason is the key role that these technologies are expected to play in reversing the downward trend in productivity growth rates threatening further development of Soviet military and civilian technologies alike. The combined impact of these issues must have served as a major stimulus to the Soviet restructuring drive.

The current restructuring program is designed to effect extensive and profound changes in the structure of Soviet economy, including the relationship between R&D and industrial production. At this time, the reform in the industrial and R&D sectors has been manifested by a series of economic and organizational measures, aimed at stimulating incentives to improve productivity and the innovation process, and involving a degree of relaxation of centralized fiscal control and changes in labor relations.

This report does not attempt to present a comprehensive review of these measures. Its focus on advanced technologies dictates a highly selective approach to the reform, addressing only those aspects of restructuring that are responsive to the special needs of advanced technologies and have a direct impact on their development. Therefore, the more general economic and administrative developments aimed at overall improvement of industry and technology are not considered in the report.

On the economic level, the report concentrates primarily on measures capable of stimulating innovation and liberating R&D organizations from funding constraints imposed by rigid state plans. On the

organizational level, the report considers the new initiatives specifically designed to promote the development of advanced technologies. So far, two such initiatives stand out: the reorganization of the Academy of Sciences intended to revitalize the Soviet computer industry under the Academy's leadership, and the establishment of the interbranch science and technology complexes (known by its Russian acronym as the MNTK), charged with the task of launching a range of advanced technologies.

The report pursues three main objectives: first, to find out how significant is the development of advanced technologies among the priorities of restructuring; second, to review the progress in implementing the particular reform measures designed to promote advanced technologies; and third, to evaluate Soviet potential for success in solving the problem of advanced technologies.

The material for the report has been drawn exclusively from Soviet publications. The resolutions of the Central Committee of the Communist Party Soviet Union (CPSU) were the primary authoritative source of data on Soviet restructuring goals and plans for the development of advanced technologies; interpretations of the resolutions and comments by Soviet officials provided further insight into the intentions of restructuring planners; and finally, field reports from Soviet industrial managers and scientists illuminated the early progress of the reform.

The seven sections and two appendices cover successively four main topics of discussion: the present situation of the Soviet R&D establishment, particulars of the recent reform measures, field reports on the effect of these measures, and the reform's potential for success. Section II provides an analysis of the Soviet R&D establishment in terms of the fundamental set of problems affecting its capability to generate new technologies; the analysis is then applied to the most important product of that capability—the Soviet technology base. The next three sections address the details of party resolutions and government measures intended to improve the performance of Soviet R&D and industry: economic reforms and choices of technologies (Sec. III), organizational reforms within the Academy of Sciences aimed at computer technology (Sec. IV), and organizational reforms creating new large-scale bridges between R&D and industry (Sec. V). Feedback from Soviet science, technology, and economics experts on the progress of these reform measures is presented in Sec. VI. The concluding section assesses the degree to which the Soviet restructuring drive can be expected to meet its goals. Readers interested in technical and structural details of the new organizations will find them in App. A (the Academy's computer development institutions) and App. B (the network of interbranch science and technology complexes).

II. THE STATE OF SOVIET R&D

SYSTEMIC PROBLEMS OF R&D

It may be useful to reduce the many complex factors underlying the shortfalls in Soviet advanced technologies to three basic categories: economic disincentives to innovation, organizational barriers, and operational deficiencies.

Economic disincentives stem from a number of features characterizing Soviet industry. The practical application of scientific research results depends first of all on the readiness of industry to translate these results into production, or, to use a technical term, to innovate. But the Soviet industrial system is strongly biased against innovation. The absence of a free market and of a realistic pricing policy based on the forces of supply and demand eliminates competition as a factor in stimulating innovation. Moscow's insistence on centralized control thwarts the incentive to innovate in individual plant managers. Rigid quantitative production quotas further stultify innovation, which requires temporary production halts for retooling and retraining. And failure to innovate, in addition to such obvious results as continuing production of obsolescent equipment, has a subtle, but profound, effect on scientific research itself by denying it information feedback from industrial production, an essential factor ensuring the ultimate practicality of scientific invention.

Although economic disincentives and their effect on Soviet industrial performance have been widely studied, Soviet organizational problems of industrial innovation are less known in the West. These problems mainly derive from the pervasive presence of jurisdictional or bureaucratic barriers in the path of the technological innovation process.

The Soviet system of translating research results into industrial products is based upon a paradox: the principle of centralization that governs many aspects of Soviet economy, often with deleterious results, does not hold in one area where it is most needed—the R&D cycle leading to advanced technologies. The Soviet R&D process is fragmented among different organizations with varying degrees of need or desire to cooperate with one another and varying administrative distance from production enterprises.

Closest to production are laboratories directly attached to production plants and designed to implement the final stages of the R&D process. The industrial research institutes involved in the middle and late stages of R&D, such as development, testing, and prototype

construction, operate separately from production plants, although they are, in common with the plants, under the jurisdiction of the industrial ministries. Furthest removed from production and from industrial R&D are the basic and applied research institutes of the university system and of the Academy of Sciences, which are entirely independent of the industrial authorities. The administrative distance between R&D and production facilities, and the jurisdictional boundaries that must be crossed by R&D projects on the way to production, turn out to be formidable impediments to an efficient innovation process.

In general, the larger the R&D input required by a technology, the heavier the penalty imposed by the fragmentation of R&D resources. The most adversely affected are advanced technologies because they require the largest R&D input and because the primary responsibility for their development rests with the Academy of Sciences, the planner, coordinator, and main performer of the relevant R&D. But the Academy is a powerful, autonomous organization that has no hierarchical linkages and weak economic linkages to the system of industrial ministries ultimately responsible for embedding the new technologies in their production. The jurisdictional barrier between the Academy and industry severely inhibits both the forward transfer of completed research projects to the production stage and the reverse transfer of information and industrial support to enhance research.

The negative influence of this barrier is further aggravated by the diverging economic expectations between the Academy, interested in maximizing the impact of its research, and the industry, interested in minimizing the effects of innovation which, in the short run, tend to decrease quantitative output indices.

The barrier problem has been the subject of extensive debate in the Soviet press for over two decades. Its persistence is striking: Many arguments currently figuring in the debate are verbatim repetitions of the paradigms of a decade ago. Soviet analysts often note the foreign industrial experience, which shows that a better interaction between fundamental science and technology is the main condition for improving the effectiveness of science. They conclude that effective research requires a single organizational structure—a unified scientific-technological complex—designed to minimize the effect of bureaucratic barriers.[2]

Another organizational problem, also partly a result of the jurisdictional barriers, has received the least attention from Western researchers—the low inter-institutional mobility of Soviet scientific and technical personnel, encouraged by institutional specialization, housing shortages, and personnel policies. Low mobility has an adverse effect on the development of advanced technologies. An ever

increasing need for interdisciplinary research efforts requires assembling experienced specialists who must be detached from assorted organizations and perhaps relocated. G. I. Marchuk, the current president of the Academy of Sciences, has emphasized this problem, noting that "World science is now based on flexible personnel teams . . . that can be quickly formed with specialists drawn from outside sources. Soviet institutions have no such mobility, but conditions for fast relocation of cadres should be created at least in the Academy's institutes." [3]

Jurisdictional barriers also impede coordination of interdisciplinary projects and the flow of information among participating organizations. Technical information flows, in turn, greatly benefit from adequate turnover of personnel, which promotes the dissemination of new ideas.

Operational deficiencies, the third category of impediments to the development of advanced technologies, result from inadequate distribution of resources along the research-to-production cycle. The most damaging of the resource problems is the absence of a proper infrastructure of experimental pilot plants in the Academy of Sciences. These plants are needed by the Academy to refine R&D projects to the necessary degree of completion before industry can start the production phase. On the other hand, Soviet industry lacks enough manpower with adequate scientific expertise to receive and process the Academy's R&D projects even when they have been completed.¹ The cumulative effect of these problems in the Soviet R&D system has impeded the smooth transition of the results of scientific research to production and delayed the introduction of advanced technologies to Soviet industrial and consumer economies. What is equally important, the systemic problems of R&D have also impoverished the Soviet technology base, a primary asset of any industrial nation. The following account of the technology base illustrates the effect of the Soviet economic system on the base's development and reveals what may be the most significant economic factor inhibiting technological development: risk-averse centralized planning.

THE SOVIET TECHNOLOGY BASE

The technology base of a nation is the accumulated inventory of technologies that are currently available to its industry for production

¹According to V. A. Sidorov, deputy director of the Novosibirsk Institute of Nuclear Physics, in many cases industry does not have specialists capable of integrating new technology into the industrial process. [4] Marchuk notes that Soviet industrial research institutes were found unprepared to absorb the results of the Academy's research, even though they receive 90 percent of the science budget, with only 10 percent going to the Academy. [3]

and to its R&D establishment for the creation of new technologies. Current availability of a technology means the operational status of the technology as a production or research tool or process, or consumer product, existing at this time. For this discussion, technology in the process of development, or even technology already developed by the R&D establishment, but not yet assimilated by industry, is not considered "currently available."

The Soviet Union maintains an inventory of nascent technologies in various stages of R&D, and particularly in the early stages of basic and applied research, that tends to match the world inventory at least in the range of research topics on the agendas of its institutes. But its technology base, as it is defined here, is considerably more limited than that of the leading Western nations. The development of a technology in the Soviet Union takes an inordinately long time² and many technologies initiated in the Academy's institutes never reach the stage of industrial innovation.

The technologies that do reach that stage are the result of concerted effort by government agencies based on their perception of need, or by *determined and influential individuals*³ able to overcome the economic, organizational, and operational obstacles on the path to innovation. But even in that case, progress may be delayed because the limited technology base may lack the necessary supporting technologies. The Soviet technology base is an accumulation of developments mainly driven by planned forecasts of anticipated needs; it thus represents an administratively directed development, rather than that fostered by new scientific or technological opportunities. As a result, a Soviet developer, facing the present need for a supporting technology, may not find it available because it was not anticipated in the past by the planners. This is the penalty for development directed from above; in the West, characterized to a greater extent by technology-driven development, many technologies exist simply because their development was feasible and marketable. Robert Oppenheimer's thought about science is sometimes also applicable to technology: "It is a profound and necessary truth that the deep things in science are not found because they are useful; they are found because it was possible to find them." [5]

The technologies that are currently missing from the Soviet technology base represent a degree of unbalance in that base relative to the West, since the gaps in the Soviet base exist side by side with highly sophisticated technologies, some of which may be on par with or

²Marchuk calls for shortening the period of development of new technology projects by a factor of three to four, and for a goal of 20 years as a maximum duration for a research project.

³See "The Initiative of the Academy of Sciences in the Computer Field" in Sec. IV.

perhaps even more advanced than their Western counterparts. A systematic account of the missing technologies is beyond the scope of this report, although it should be an instructive, if difficult and labor-consuming, research venture. Here we merely recall some of the outstanding cases of technologies whose absence had delayed, if not stopped altogether, the progress of important Soviet projects.

A well-known case of this kind is the recent Soviet purchase of automated multi-axis grinders from Japanese and Norwegian companies for shaping submarine propellers. The submarines in question, notoriously noisy by Western standards, represented advanced Soviet technology but lacked a critical element necessary to make them quiet. The propeller-quieting technology, apparently unanticipated, just was not there.

In the 1970s, the Soviets had built the world's first operational magnetohydrodynamic (MHD) power plant, the U-25, to serve the electric power needs of the city of Moscow. A research program for further development of the MHD system and for upgrading the plant required the installation of a superconducting magnet at the plant. Although the research institutes of the Soviet Academy of Sciences had for years maintained programs for superconductor technology, an advanced superconducting magnet system had to be flown in from the United States because it was not locally available.

Progress in the experimental laser fusion program at the Lebedev Physics Institute had been delayed for many years because of parasitic energy losses in the neodymium glass amplifiers of the laser system. Early designs of laser fusion systems envisaged glass rods as the lasing medium to be traversed axially by the laser beam. However, research soon showed that losses could be reduced by a shorter beam path through the same volume. This called for large-diameter slabs instead of rods. While the corresponding U.S. program switched to slabs, the Soviets continued to use the rods for lack of slab surface coatings of the necessary optical quality.

The development of Soviet pulsed-power technology, commenced years ahead of the West, has been hampered by the lack of reliable high-energy capacitors with sufficient energy storage density. Shortage of these devices, available in the West at the time, was a factor in the Soviet quest for inductive storage systems which may yet prove to be the superior solution in the development of directed-energy technology. This may be one of the interesting, albeit few, cases in the history of Soviet technology where an inherent weakness ultimately turns out to be beneficial to the overall development.

Soviet use of "hard" electronic tubes, continued well beyond the time when the West switched to solid-state devices, might be a good

illustration of the delaying effect on technological progress by military decisionmaking. It is conceivable that the greater vulnerability of solid-state materials to ionizing radiation caused Soviet military planners to prefer tube technology and thus to delay the development of Soviet solid-state electronics. The success of the Silicon Valley phenomenon illustrates the advantage of the economic system that allows free play for risk-taking entrepreneurs.

The most striking example of the limitations inherent in the Soviet technology base is the problem of Soviet computer technology. Much has been written about the complex nature of this problem, but it is clear that a major cause is the lack of a broad range of supporting technologies and the low reliability of many that are available. Soviet analysts have noted the considerable Soviet lag in microelectronics, a critical supporting technology for computers which, in turn, have been hampered by deficiencies in supporting technologies such as chemical technology, materials processing, and lithography.[2,6] According to A. M. Prokhorov, Secretary of the Academy's Department of General Physics and Astronomy, the lag will keep increasing without such support.[6]

Development of very large system integration (VLSI), one of the great achievements of microelectronics, requires suitable software to design a VLSI model according to specified architecture and taking into account available technology with all its possibilities and limitations. Such a software system—the so-called silicon translator—is not available in the USSR. In fact, according to Ye. P. Velikhov, vice-president of the Academy of Sciences, software industry does not yet exist in the USSR.[7]

The lag in microelectronics has led to deficiencies in Soviet microprocessor technology, with a far-reaching impact on a wide range of Soviet industries. One of the directly affected areas is the Industrial Laser MNTK, which is experiencing considerable difficulties with the construction of prototypes and production models without microprocessor technology to control the laser.[7]

On the other hand, Soviet-made microprocessors were said to have assured the successful flights of the Vega-1 and Vega-2 space probes, enabling them to function without breakdown for 15 months.[8] Thus, while reliable microprocessors may exist in the Soviet technological inventory and be available for space ventures, they may not be generally available to the industry.

Soviet laser development is also affected by deficiencies in optics technology. According to N. T. Stavrukov, optics is the greatest stumbling block today in the development of laser technology.[9] Prokhorov notes that the service life of industrial lasers is now 1000 hours. He

would like to extend it to 2000-3000 hours, although he claims that lasers purchased abroad work considerably longer.[10]

Soviet lag in fiber-optics cable communications and television is attributed to problems in the development of electron-optics devices and the absence of high-quality fiber-optics industrial production technology.[6]

The above examples illustrate the way in which gaps in the Soviet technology base affect the development of other technologies: the gaps tend to multiply in a kind of chain reaction mechanism. The gaps are the inevitable consequence of rigid planning which cannot be expected to forecast accurately all future technological needs and to devise a rational and workable schedule for their synchronization with developing technological opportunities. It is the irony of the Soviet system that a planned economy not only causes the gaps but also makes it difficult to fill them early enough. The excessively long period of the Soviet R&D cycle, the economic disincentives to innovation, and the interagency barriers conspire to inflate the time penalty for failing to predict a needed technological development.

The case of the Soviet technology base also shows that excessive adherence to administratively directed development may well prove to be a far more profound impediment to technological progress than the economic disincentives and bureaucratic barriers discussed above. It may also be far less tractable an impediment than the other factors. Development stimulated by new technological opportunities, or the "technology-driven" mode, entails considerable risks that are not compatible with a rigidly planned economy. Its indispensable requirement is the availability of free risk-taking entrepreneurs willing and able to exploit opportunities in creating new marketable technologies. But the Soviet economic system has so far excluded such entrepreneurship.

Because the Soviet economy and especially its civilian sector is not as large as that of the United States, the Soviet technology base cannot be expected to match the scale and variety of U.S. technology. In particular, the Western-style risk-taking entrepreneurship could not proliferate technologies as lavishly in the smaller Soviet civilian economy as it has in the United States. Nevertheless, independent risk-taking and its associated technology push, as opposed to rigid planning, still represent the mechanism that could most effectively minimize the gaps in Soviet technology base.

The leadership of Soviet R&D is well aware of the need for this mechanism. As put by S. P. Yefimenko, the deputy chairman of the State Committee for Science and Technology (GKNT), speaking about research institutes facing restructuring reform:[11]

The old days were like this: you got a scientific idea that promised important results in the future, and you either went to the ministry to plead for funds, or you looked for a customer willing to risk supporting your research. But under the new conditions, you will have your own money and will have to decide for yourself whether or not to take the risk.

Heretofore, the ministries or other such "customers" bound by state plans have been unlikely to have unallocated excess funds to support new scientific ideas whatever their potential might be. Even if such funds were available, the bureaucratic ministerial apparatus would be most unwilling to shoulder the burden of risk inherent in financing untested and unforeseen ventures. As will be shown below, restructuring does not appear to promise a proliferation of institutes with "own money" for such ventures on a scale sufficient to invigorate the Soviet technology base.

The restructuring drive attempts to deal with the problem of opportunity costs of R&D within the framework of economic reform, as well as with the organizational and operational obstacles to innovation. The next three sections examine the specific measures adopted to improve the innovation process and the development of advanced technologies.

III. THE TECHNOLOGICAL MODERNIZATION REFORMS

TECHNOLOGICAL PRIORITIES

Gorbachev's restructuring reform was formulated at the April 1985 Plenum of the Central Committee, CPSU, as the concept of accelerating the socioeconomic development of the country through scientific and technical progress.[12] The concept was approved in March 1986 by the 27th Party Congress and published as a resolution of the Congress in *Izvestiya*. [13] The resolution is worth a detailed analysis since it features what appear to be specific government plans for the development of advanced technologies.

The focus of the resolution is a program entitled, "Main Directions of Economic and Social Development of the USSR for the Years from 1986 to 1990 and for the Period to the Year 2000." The Program states at the outset:

The highest aim of the party's economic strategy has been and remains a steadfast rise in the material and cultural standard of living of the people. The realization of this aim during the forthcoming [15 year] period calls for the acceleration of social and economic development, and all the necessary means to intensify and to increase the effectiveness of production, based on scientific and technical progress.

"Scientific and technical progress" thus emerges as a key phrase of the resolution, implying that R&D and industrial innovation, the basic engines of such progress, should play a principal role in Gorbachev's restructuring effort.

The text of the Program consists of 14 sections analyzing the state of the Soviet economy and plans for future social, economic, agricultural, and industrial development of the country. In keeping with past Soviet practice, the Program does not include military issues. Materials relevant to the development plans for specific technologies, and particularly advanced technologies, are confined to Section 4 (on science and technology) and Section 5 (on heavy industry). The plans dealing with the light industry (Section 7) and transport and communications (Section 8) contain no technological detail of interest. Consequently, the two sections, 4 and 5, remain the only loci of substantive technical information in the resolution of the Central Committee on the plans and expectations of Soviet leadership about R&D, industrial innovation, and the development of advanced technology.

Section 4—"Acceleration of the Scientific and Technical Progress and Development of Science"—lists the main areas of advanced technology applications in industry, defines the status of the two principal science organizations [the State Committee for Science and Technology and the Academy of Sciences], and deals with the performance of industrial R&D and the organizational structures bridging the gap between R&D and industrial production.

To assess the impact of restructuring on the development of advanced technologies, one must consider Soviet priorities assigned to specific technology areas and the range of technologies involved in the restructuring plans. Section 4 first calls for concentration of resources on the following "important directions of scientific and technical progress": the development of electronics, atomic energy, systems automation, and the technology of production and treatment of new materials. Next, it calls for "... broad dissemination throughout the national economy of new-in-principle technologies of electron beams, plasma, pulse [*impul'snykh*], biology, radiation, membranes, chemistry, and others, which allow for many-fold increases in labor productivity, enhance capitalization efficiency, and decrease energy and material requirements for production."

Other technology goals of Section 4 are as follows:

- Broadly disseminate methods of biotechnology and genetic engineering.
- Introduce automated systems into various sectors of national economy, particularly into design and equipment and process control.
- Organize mass production of personal computers, increase the use of modern high-speed computers of all classes, and continue to introduce and increase the efficiency of time-shared computer centers, integrated data banks, and information processing networks.
- In developing new technology, make wider use of materials with preassigned properties, such as synthetics, composites, and ultrapure materials.

Section 4 also devotes space to basic research, urging the expansion of those areas of basic research that provide for "profound qualitative changes in production capacity and new-in-principle kinds of production, equipment, and technology." But it does not specify these areas and it does not address applied research and development, the stages of the R&D cycle that are essential to the creation of advanced technologies.

Section 4 thus notes the need for developing broad areas of technology (electronics, for example) and for more extensive use of specific technologies that presumably are already available. The list of these technologies is somewhat unusual and merits attention: electron-beam, plasma, and radiation technologies are used for the treatment of materials and include advanced techniques in the fabrication of microprocessors. However, they hardly qualify for inclusion in a short list of the most important new technologies. The most puzzling is "pulse" technology; no technology known in the USSR or in the West can be readily associated with this term, except for pulsed power.

But these technologies are clearly important to restructuring planners: three of the seven technologies listed in this context, the radiation, pulse, and filtration membrane technologies, represent the recently organized large R&D and production organizations—the inter-branch science and technology complexes (MNTK)—that are expected to solve the problem of developing advanced technologies.

Section 5, on plans for modernization of heavy industry, offers further clues to assess the prospects for near-term advanced technology development. All such indications are concentrated in the machine-building part of the section.

General technology areas assigned top priority in machine building are machine tools, computer technology, instrument construction, and the electric power and electronic industries. The growth rates of these areas are expected to exceed the average growth rates of machine building as a whole by a factor of 1.3 to 1.6.

But the detailed listing by sector of technology development targets in the machine-building area has significant omissions: no separate sector is assigned to computers, and no mention is made of electronics as a distinct industry. The latter and other highly important advanced technologies are noted only in passing or in connection with some of their applications.

Thus, broad use of automation based on microprocessor technology is planned for the electric power, heavy machinery, and machine tool sectors. But there are no plans for large-scale development and production of the microprocessors themselves, in short supply in the USSR. The plan for the electrotechnical sector specifies the production of solid-state power devices, fiber-optics cables, and 10-kW laser material-treatment stands. Plans for computer production are included in the instrument-building sector, but they are limited to small fast computers, personal computers, very large system integration (VLSI), and software. There is no mention of radio, television, electron-optics, or modern telecommunications technologies. Neither do these technologies appear in the other logical place—Section 8 of the Program,

which deals with the development of transportation and communications, and which is almost entirely devoted to the several forms of traditional transport, leaving only three lines to the pressing problem of modernizing Soviet communications.

The most striking impression of the "Main Directions" Program is that it pays much less attention to the development and manufacture of advanced technology products than to their application and dissemination. Development is not explicitly addressed in the Program at all, and none of these technologies appear as separate industries in their own right.

The fact that electronics, computers, and instrumentation are relegated to the category of machine building, and hence to heavy industry, underscores their inferior status in Soviet industrial taxonomy and reveals a conservative mindset of Soviet planners who continue to think in terms of the old categories.

The Program includes only a brief note on the functions of the MNTK network that is to take over the development of advanced technologies. But the MNTKs show the same omissions and the same bias toward traditional technologies as those found in the text of the Program.¹

Another omission of the Program is the lack of any reference to the 1983 reorganization of the Academy of Sciences in the computer field and to the ensuing initiative of the Academy in guiding industrial development of computer and microprocessor technology, described elsewhere in this report.

A plausible explanation of these omissions would attribute their cause to poor coordination and haste in preparing the Program plan stemming from the Soviet leadership's evident pressure to implement restructuring as soon as possible. An alternative view, however, could be based on the assumption that advanced technologies, such as computers, electronics, and telecommunications, are of primary importance to the military and that detailed plans for the development of these technologies may have been diverted to a hypothetical military version of the Program that has not been published. It would be reasonable to expect that the restructuring drive, with the broad ramifications demonstrated daily in Soviet press, should not be limited to the civil sector. Although Soviet military technology, unlike its civilian counterpart, has so far been able to satisfy national requirements, its future ability to do so is threatened by the increasing dependence of weapons systems on advanced technologies and the continuing Soviet weakness in this area. Thus, an accelerated program of advanced technology

¹See "The MNTK System" in Sec. V.

development for military applications confined to classified military establishments would be a possible but unlikely alternative to a national program.

On its face, the Program appears to have been drafted by a highly traditional industrial bureaucracy which, while paying lip service to scientific and technological progress, continues to pursue the old-style industrialization policy which has always emphasized heavy industry and machine building.² Such a policy gives more emphasis to machine tools and other components of heavy industry than to electronics and similar advanced technologies.

This impression of bureaucratic traditionalism, if not outright resistance to modernization within the restructuring program, is further supported by Soviet critics of the way the program has been implemented so far. Critics claim that technological modernization is being resisted by the bureaucracy running the national economy and by industry (see Sec. VI on reform results).

A. G. Aganbegyan, the leading exponent of the current economic reform, acknowledges the bias toward traditionalism at the expense of modernization, which he sees in terms of evolutionary and revolutionary approaches to science and technology: evolutionary development of existing equipment and technology, and revolutionary transition to new-in-principle technologies and new generations of equipment. In his view, since the revolutionary approach requires extensive investment and time, the evolutionary approach has so far been dominant.³ The enormous capital investment for modernization made during the 12th Five-Year Plan is therefore expected to show its effect in revolutionary development only during the 13th and 14th Five-Year Plans.[15]

Limitations of Soviet technology have also been discussed in relation to technology transfer from abroad. Although the resolution of the 27th Congress does not include technology transfer, B. Ye. Paton, president of the Ukrainian Academy of Sciences, stated that the Congress had addressed this problem, urging utilization of native Soviet scientific and technical potential and branding as unacceptable

²In the 12th Five Year Plan (1986-1990), machine building is the primary target of the Soviet industrial modernization effort, with a slated increase of 40 to 45 percent in machine-building production, almost double the increase planned for the entire Soviet industry. The modernization of machine building, based on the transition from extensive to intensive enhancement of productivity, is considered the springboard for technological modernization of the industry as a whole.[14]

³The conservative cast of Soviet thinking about technology is apparent even in Aganbegyan's own terminology: he considers the diesel passenger automobile a "revolutionary" development. In providing a typical example of the persistence of the evolutionary approach, Aganbegyan cites the continuing production of gasoline-powered automobiles by the Gor'kiy Automobile Plant; the scheduled revolutionary transition to diesel power will be realized only after several years and heavy conversion expenses.[15]

the preference of imported over domestic technology. According to Paton, requests for foreign technology have been increasing every year.[16] In this connection, it was noted that Soviet inferiority in any one of the decisive areas of science has caused a lag in the corresponding sector of the national economy and has led capitalist countries to restrict information exchange in such areas in order to compound Soviet difficulties further.[17] Furthermore, the need for new technology should not be estimated from comparisons with the West, but only on the basis of Soviet industry's readiness to use the technology.[4]

STIMULATION OF ECONOMIC INCENTIVES

Progress of advanced technology in the Soviet Union depends, more than any other issue, on an effective reform of the economic system that would provide enough incentives to industrial innovation. While new technologies are generated by science, their successful development and, above all, practical application depend entirely on the willingness and ability of the industry to innovate, i.e., to assume the risk of retooling, retraining, and launching a new product, often at the expense of old production levels. Although the 12th Five-Year Plan sets aside over 200 billion rubles of capital investment for technological modernization, which is more than was expended for this purpose during the past 10 years,[14] it is not clear how much the current economic reform will stimulate the development of advanced technologies. Much of this investment already appears to be earmarked for the improvement of traditional technologies (note the "Main Directions" Program, discussed above), rather than toward launching what the Soviets call new-in-principle technologies.

In addition to the input of new capital, it is the series of departures from past Soviet economic practices and regulations, designed to provide effective incentives to innovation, that should determine the prospects for Soviet advanced technologies. These departures are embedded in the planned transition from extensive to intensive⁴ development, requiring total self-support, self-amortization, and self-financing of all production enterprises.[3]

The dichotomy of extensive versus intensive economic development has been a central feature of the restructuring reform. In the extensive mode of development, characteristic of the past and much of the present Soviet economy, growth of output is achieved by ever

⁴Decisions to shift to intensive economic development have been made before. A resolution of the 26th Party Congress called for a "decisive transition to primarily intensive factors of economic growth . . ."[18]

increasing inputs of energy, materials, capital, and labor. But the growing constraints on the ready availability of natural resources and the unfavorable demographic trends have been making it increasingly difficult to maintain output growth rates. The intensive mode, on the other hand, postulates higher growth rates of output achieved by higher efficiency of input utilization, rather than by more inputs. This, in turn, would be obtained by the introduction of new technologies and new principles of management organization. Along with waste and depletion of inputs, the most detrimental practical effect of the extensive mode on Soviet economy is that it severely discourages innovation and rewards sheer quantitative output. Transition to the intensive mode is expected to reverse these impediments. But transition itself depends on innovation incentives to obtain the new technology; therefore, innovation incentives must first be introduced by administrative fiat, a condition difficult to realize under the Soviet system.

According to Aganbegyan, the first step in this direction should be to adopt a realistic pricing policy.[14] Other issues to be considered involve profitability and profit disposition, credit policy, centralization versus local autonomy of planning and management, work compensation, and subsidies versus self-support of enterprises.

Analyzing more specialized issues, Aganbegyan notes that the shortage of industrial goods, forcing the consumer to accept whatever is being offered, is caused to a considerable extent by the present system of centralized distribution of production resources. Therefore, he assigns high priority to the transition to wholesale trade and direct horizontal relations among enterprises and associations. This, he thinks, is possible only after a radical restructuring of the system of prices and credits which, in turn, requires fundamental preparatory work of at least two to three years.[15]

The members of Soviet academic leadership have voiced even more radical views on the kind of necessary economic incentives.

G. I. Marchuk, president of the Academy of Sciences, USSR, defines profit as the only valid criterion of enterprise activity, the real source of the life of the collective, and the indicator of success of its work.[3]

According to L. I. Abalkin, director of the Institute of Economics, Academy of Sciences, the thesis that private property hampers, and public property stimulates modern production forces is necessary but insufficient for the understanding of economics. Experience has shown that public property by itself does not guarantee success and, when the concept is allowed unrestricted sway, it can generate obstacles to production forces. Public property should thus assume different forms corresponding to changing economic conditions.

Abalkin listed the following goals of the reform:[19]

- Satisfaction of human needs instead of satisfaction of the administrative process.
- Individual and organizational competitiveness.
- Rewards for achievements without theoretical limits coupled to progressive taxation.
- Placing responsibility for results on individual workers as well as on the administration.

The last goal has been spelled out in detail by K. Turysov, secretary of the All-Union Central Council of Labor Unions, who phrased it as the "human factor in the strategy of acceleration." [20]

According to Turysov, the increases in wages and premiums for production-sector workers, scheduled for the 12th Five-Year Plan, will for the first time be realized from the earnings of the enterprises. Centralized funds will be, in the main, used to increase the wages of workers in the services sectors.

The earning principle of wage setting will be extended to individual collectives and work brigades, which will be paid according to work results. One of the new methods of determining individual wages is the KTU (*koeffitsient trudovogo uchastiya*—labor participation coefficient), which determines wages according to the quantity and quality of work contributed by the collective.[20]

On the face of it, the principle of KTU with its financial accountability for performance comes perilously close to a piece-work payment system and can be expected to become a major source of resistance to the economic reform. Although KTU represents an extreme example of the proposed reform's impact on the established order of labor relations in the USSR, the Soviet leadership must consider the potential such changes will have in disrupting the political system.

At the 1987 general meeting of the Academy of Sciences, academician V. V. Struminskiy analyzed this problem as the result of the current incompatibility between the Soviet economic system and a Soviet society not mature enough to use the system.[21] Therefore, the choice is between retaining the economic system and concentrating all efforts on transforming society ("restructuring the social consciousness of the nation"), or changing the economic system along the lines proposed by the reform. The implication was that the latter alternative was much more realistic.

Struminskiy added that fundamental problems of this type have not been studied by the Academy so far, but now demand priority attention in the light of the resolutions of the 27th Party Congress.

TRANSFER OF R&D TO A SELF-SUPPORTING BASIS

The economic reforms of the Soviet R&D system have been reflected in the decision of the Central Committee and the Council of Ministers to place R&D organizations on a self-supporting (*khozraschet*) and self-financing basis.[22] The decision was approved by the Politburo on September 17, 1987, to be implemented in 1988.[11] In the official text of the decision, the Central Committee noted the "insufficiently effective utilization" of the national R&D potential, "lag in a number of important R&D areas," and "failure to secure a leading position for [Soviet] science and technology" in the light of the scientific and technical revolution that has been taking place in the world. It also placed the blame squarely on GKNT, the Academy of Sciences, and the industrial ministries for tolerating a low quality of R&D, neglecting to focus resources on priority R&D areas, and failing to supervise properly their R&D organizations.[22]

The decision of the Central Committee amounts to a revolutionary change in the economy of the Soviet R&D establishment. For the first time, an official declaration of the Soviet government states that profit will be the basic source of capital investment and wages of R&D organizations.

Beginning in 1988, R&D organizations will no longer be supported by state budget funds; the contribution from the latter to R&D organizations will be considered only on a case-by-case basis. State budget distributions for R&D will be controlled by GKNT and will support major theoretical research projects, interbranch R&D projects of national importance, and the development of new-in-principle technologies capable of revolutionizing production.

R&D organizations will be supported by goal-oriented financing of specific research and development projects, based on contractual agreements with interested user-sponsors. The sources of such financing will be the funds of sponsoring associations, enterprises, and other organizations, as well as the centralized funds and reserves of ministries and agencies, and bank credits; only when it is unavoidable, will state budget financing be used.

The contractual prices for R&D, pilot production, and technical services will be subject to agreement with the sponsor prior to commencement of work and will depend on the required effectiveness, quality, and time goals. Cost overruns incurred without the sponsor's permission will be borne by the contractor.

A contractor failing to honor his contracted obligations will return the funds to the sponsor and will be subject to fines specified by the contract and appropriate laws.

The R&D organization will cease its activities if it fails to find user-sponsors, performs long-term fruitless work, or its operations fail to yield positive results.

The new rules, however, do not mean that R&D organizations will be more autonomous from now on; the decision of the Central Committee also calls for strengthening the responsibility for and control of the R&D organizations by GKNT, ministries, and agencies.

The degree of control over revenues derived from profits and the overall management autonomy of the R&D organizations will vary, depending on the type of jurisdiction supervising these organizations. The following types of jurisdictions are recognized: the Academy of Science and university system, ministries and agencies, production associations and enterprises, science-production associations (NPOs), and MNTKs.

R&D organizations that belong to the Academy-university systems are to receive payments for work done directly from the user-sponsors. However, their freedom to engage in basic research appears restricted by the overall objective to "establish theoretical foundations for new-in-principle technologies capable of revolutionizing production" and to cooperate with industrial R&D organizations in exploratory and applied research of an industrial nature.

R&D organizations directly subordinate to ministries and agencies appear to have the greatest degree of management autonomy and control over profit distribution. They are free to determine the volume of contractual work for the creation, production, and delivery of new technology and services, and they have the right to use profit revenues for speculative exploratory research. But their profit revenues must bear the burden of state taxes for the use of state production funds, labor and natural resources, deductions for local and state budgets, and contributions to the central state capital investment fund and to ministry reserve funds. The R&D organization will use what remains of the profit for its own capital investment fund, foreign currency fund, and the wage and bonus fund, which is treated as residual, after subtraction for capital investment.

On the other hand, profits earned by R&D organizations within production associations and enterprises will not be retained by them, but will be included in the total profit of the associations, treating the support of R&D as part of the cost of production. Allocation of profit from R&D in the NPOs is not clear; the text merely states that "R&D organizations within the NPOs act as structural units or independent organizations subject to USSR laws on state enterprises." The next paragraph says that the NPO manages its independent R&D organizations, performing the functions of a supervisory administration.

The status of MNTKs is not specified in the decision, probably because of the disappointing performance of these organizations; the text of the decision merely notes that "the entire work of the MNTKs should be reorganized in the the shortest possible time."

The above rules governing profit allocation and the extent of autonomy granted to the R&D organizations seem to diminish the promise inherent in the transition to a self-supporting mode, particularly in the production associations. The associations' insistence on the priority of production was the factor most responsible for inhibiting R&D. Their control over profits of the R&D organizations is sure to perpetuate this factor. The potential inhibition of R&D in spite of the reform is all the more significant, because industrial R&D organizations are to be concentrated in the associations. The decision of the Central Committee explicitly states that, as a rule, R&D organizations should be a part of the associations and can remain outside only in exceptional cases.

GKNT, the organization sharing the interests of science more than those of industry, emphasizes the liberating effect of the new policy on R&D. Yefimenko, the deputy chairman of GKNT, provided a detailed interpretation of the Central Committee decision.[11]

According to Yefimenko, the basic principle of the decision is that the result of scientific research is given the status of a commercial product which must be paid for by the consumer. This is in contrast to the previous system whereby R&D organizations have been supported by the state budget regardless of their output, much of which was available at no cost to users. In 1987, the state outlays allocated to the support of industrial research institutes and design bureaus exceeded 30 billion rubles.

The new operating basis of total self-support and self-financing means that every research task and project will be subject to a contractual agreement between the R&D institute—the contractor—and the industrial or other sponsoring organization, based on direct negotiations between the contracting parties. Such an agreement will be the only document controlling the relations between R&D establishments and their sponsors. The R&D establishments will also have to compete and bid for orders from the user organizations.

The entire system of research planning will be changed. The volume of work an R&D institute may expect will depend exclusively on the volume of contracts it can acquire. The funding pattern will change and will consist of three sources of funds for R&D: customer funds, bank credits, and own funds of the R&D institutions derived from profits. The latter will be used to buy equipment, improve housing, award bonuses, and so forth. The R&D institutions will be

allowed to keep and control a substantial share of the hard currency acquired from exporting their output.⁵

The R&D institutions will guarantee their contractual obligations with their profits. The relationship of profits to wages will be regulated in one of two possible ways. One way will be to standardize wages and to include them in the cost of production. Any losses reducing profits will not affect wages but only the bonus awards. In the other way, wages will depend entirely on profits and on the individual worker's contribution to the profit.⁶ The choice between the two ways will be made by the relevant ministry for each institute.

Beside industrial orders, the R&D institutions will receive state orders from the ministries and agencies (probably including the military). State orders will command priority and will include major R&D programs. They will be paid from centralized funds of the ministries and agencies, and will provide special incentives. Orders for inter-branch R&D will be granted by agencies and the State Committee for Science and Technology.

There will probably be many unresolved issues left in the wake of the Central Committee's decision to place R&D institutions on a self-supporting basis. The most obvious is the long habit of bureaucratic domination over industrial R&D and of the total dependence on the part of R&D managers. As Yefimenko points out.

The ministry workers are used to domination over industrial R&D which cannot make a step without proper signatures and paragraphs. The institute leaders, on the other hand, are not used to independence . . . and need a collar and a leash in order to blame the leash-holder for problems.[11]

Another such issue is the problem of setting contractual prices. If the principle of direct contractual negotiations includes prices for proposed work as negotiable items, the new system comes close to permitting free play of market forces. GKNT, represented by Yefimenko, favors this interpretation. But Yefimenko implied that the industrial ministries may disagree.

Finally, it is not clear to what extent the new economic system will affect the institutes of the Academy of Sciences and, consequently, its temporary laboratories, interagency and engineering centers, and NTKs. Yefimenko states that "contractual subject areas (*dogovornaya*

⁵Yefimenko thus bypasses the constraints on profit distribution and autonomy of R&D organizations spelled out in the text of the decision of the Central Committee. He obviously has additional knowledge of the new policy that may permit a more liberal interpretation of the text.

⁶Note the use of the "labor participation coefficient" described above.

tematika) of [the] Academy's institutes and universities will be governed by the same rules as industrial science. The state will then support only institutes active in basic research and the humanities, and those not directly relevant to industry." [11]

Academy institutes performing research in natural sciences and engineering that are "relevant to industry" have been supported mainly by state allocation for science and science service, and also by direct contracts (*khozdogovory*) with industry. The contractual share of total support of such institutes has been kept at an average level of about 20 to 30 percent, reaching well above 50 percent in some cases in the Ukraine and the Siberian Department of the Academy. But much of the state-supported work of these institutes has a direct technological and often military significance. [23] Thus, this large area of activity of the Academy's R&D appears unresolved by the reform at this time. If it is allowed to remain that way, the Academy may suffer from the competition of the "liberated" and therefore potentially more aggressive industrial R&D organizations.

IV. RESTRUCTURING AND THE ACADEMY OF SCIENCES

"Acceleration of scientific and technical progress," the ubiquitous phrase in the rhetoric of restructuring,¹ refers to a new emphasis on R&D and advanced technology, and hence on the Academy of Sciences, the principal contributor to the development of advanced technology. Consequently, a major thrust of restructuring R&D and industry has been to include the Academy and its institutes in many of the new organizations designed to integrate R&D and production.

To appreciate the significance of the Academy of Sciences and its research institutes to the technological objectives of restructuring, it is necessary to take a closer look at the role played by the Academy in the Soviet R&D establishment.

In the industrialized West, two categories of institutions play major roles in R&D: universities performing basic research and industry. Industry takes care of the remaining stages of the R&D cycle, including the work required for the effective transfer of R&D results to the production stage. The Soviet Union has added a third major category of R&D performer: the research institutes of the Academy of Sciences, which like the universities represent an autonomous system independent of the industry.

Broadly speaking, the Soviet R&D establishment thus consists of university research institutions, the Academy of Sciences system, a relatively small number of research institutes of other independent institutions such as the State Committee on Atomic Energy, and the industrial R&D network. The latter includes the bulk of Soviet research organizations, such as research institutes, design bureaus, and production plant laboratories, all operating under the industrial ministries. The number of industrial research institutes is probably an order of magnitude higher than that of the Academy system, and the two

¹The rhetoric also makes much use of such terms as "fundamental science" and "branch science." The former denotes the research institutes of the Academy of Sciences and the products of their work, even though this work may often progress far beyond what is considered in the West as fundamental science and include all the stages of the R&D cycle down to prototyping, or to the point where the effort should be taken over by the industry. The term "branch science" is more often engineering than science and covers the industrial research institutes associated with the industrial ministry system. The main task of the Academy of Sciences is research that culminates in new-in-principle devices, processes, technologies, and materials whose ultimate practical application is achieved with the aid of industrial institutes.[3]

categories of institutes differ, at least nominally, in the kind of research they perform. The Academy research is supposed to be focused on basic science and the early stages of R&D, whereas the industrial institutes are intended to cover the later stages, closer to actual production.

However, the role of the Academy of Sciences in Soviet R&D transcends the limits of size and nominal function for at least two reasons. First, the Academy institutes employ the elite of Soviet scientists, in terms of talent, reputation, and the sheer concentration of advanced academic degrees, leaving the industrial institutes far behind. The concentration of top scientists in the Academy of Sciences is illustrated by the fact that its Institute of Radioengineering and Electronics and the Lebedev Physics Institute alone employ almost the same number of PhDs as their totals in the entire electronics and communications industries.[24] The number of PhDs in the Ministry of Electronics Industry is lower than that employed at the Academy's Institute of Chemical Physics alone.[2,25]

Second, the Academy's scientific and engineering talent resides in many areas directly relevant to the development of advanced technologies,[2,25,26,27] including automatic computer design methods, solid-state and microelectronics technology, advanced material processing and metallurgy technology, genetic engineering, magnetohydrodynamics, and pulsed power or high-density energy technology. The latter drives the development of lasers, high-power microwave devices, and high-current particle beam generators, and is essential to the realization of controlled fusion reactors, directed energy weapons, and many aspects of space defense objectives.

The Soviet Academy of Sciences, therefore, emerges as a principal national resource in the development of advanced technologies, and hence as a significant contributor to the Soviet defense potential. It is a unique organization in the world of science; as an independent and nearly exclusive performer of the most advanced research in the nation, it has no counterparts in other industrially developed countries.

The dominant and autonomous position of the Academy in Soviet research has not, however, been entirely beneficial to its own, or indeed the national, interest. The separate existence of the Academy has disrupted the introduction of its research results into industry. At the same time, its tendency to absorb and concentrate national scientific talent within its ranks has deprived industry of the necessary level of resident scientific expertise, and, conversely, has impaired the technological support the Academy can expect from the poorly qualified industry.

The power to draw the best scientists stems from the well-earned prestige and privileges of the Academy of Sciences, and from its position as the principal site of basic research in the USSR. But the Academy has failed to challenge the implicit premise that basic research must have first claim on the best scientists, or that top scientists are wasted on industrial research. Neither has the Academy made a serious effort to increase the low mobility of its personnel or to divert scientists to industry.

In addition to the impact of the Academy, the distribution of Soviet scientists has been skewed by the old cultural bias in favor of theoretical science and the scarcity of experimental equipment, creating an excess of working theoreticians. The resulting scarcity of experimentalists, the pull of the Academy, and the overproduction of engineers² by Soviet universities have starved Soviet industry of scientific talent.

A serious problem threatening the scientific eminence of the Academy of Sciences has been the extraordinary aging process that overtook its leadership during the last decade. This is illustrated by the age distribution of the 274 full academicians[29] within a 10-year period:[30]

Academy members younger than 50 years

1976	5.8%
1986	0.8%

Academy members older than 75 years

1976	15.3%
1986	36.6%

The astonishing fact that the Academy has about 100 leading members over 75 years old can be ascribed to their lifetime tenure. But the fact that only one academician³ is younger than 50 reflects the poor turnover and election policies of the Academy.

²G. A. Yagodin, USSR Minister of Higher and Secondary Specialized Education, notes that while the USSR graduates almost as many highly qualified specialists as does the United States, there are 3.8 times more engineers in the USSR than in the United States and the USSR graduates 3.1 times more engineers per year than does the United States. However, only 14 non-engineering specialists are graduated for every 10 engineers in the USSR, as compared to 32 in France, 37 in West Germany, and 114 in the United States. Yagodin questions the Soviet need of so many engineers at their present qualification level.[28]

³Identified as S. P. Novikov.[31]

Marchuk has recently reported that age limits on Academy leadership are being introduced. All scientific workers, except academicians and corresponding members of the Academy of Sciences, must resign their administrative posts upon reaching the age of 65. This includes directors, deputy directors, and chiefs of laboratories, departments, and sectors. Members of the Academy, in view of their high qualifications and work experience, will have to resign from leadership positions between the ages of 65 and 70 and will then be limited to research and training. It is also planned to rejuvenate the membership of the Academy's institutes without increasing their numerical strength (housing is a problem).[32]

Another major problem concerns the basic policy and mission of the Academy. A source of considerable conflict within the ranks, the problem stems from the perception of the two roles the Academy is to play: pursuit of independent basic research and involvement in industrial innovation. Some academicians believe that the Academy should be dedicated entirely to basic research—to science itself. This position implies more independence for the Academy, albeit at the cost of diminished political power and influence in national affairs. Others favor more involvement with industry and an attendant rise in income and influence, even at the cost of some loss of independence.

The history of the Academy reflects this conflict and reveals wide swings in Academy orientation between the two positions. During World War II, the Academy was heavily engaged in defense work and, during the late 1940s, in the development of nuclear weapons. The 1950s marked a swing toward basic research, culminating in the transfer of many Academy institutes to industry in 1961. Since that time, spurred by the government's concern with industrial conservatism and the promise of contractual funding, the Academy has been steadily regaining lost ground in the shift toward applied research and development.

The reforms have intensified the recurring anxieties among Academy members about the integrity of science and the threat of industrialization of the Academy. In a picturesque, if physically inaccurate, expression of these apprehensions, academicians I. M. Gel'fand and L. M. Brekhovskikh compared science to an iceberg whose tip was applied science and the submerged part was basic science. Excessive melting of the submerged part could very well "sink the whole iceberg." [33,34] As an example of such melting, Brekhovskikh cited Academy institutes dedicated to earth sciences that are without resources because funds have been diverted to technology-oriented research. As a result, accurate weather forecasting, even for one day ahead, is no longer available.[34]

Nevertheless, the current economic and industrial reform, as spelled out in the "Main Directions of Economic and Social Development" Program[13] and in the statements of Soviet leadership, has firmly committed the Academy to massive interaction with industry. But the language of the Program has retained the old ambiguity between the role of the Academy as a basic research organization and as a promoter of industrial innovation. On the one hand, the Academy will "give priority to the development of basic science and will assume greater responsibility for the quality of its own R&D." But it will do so to "create theoretical foundations for new-in-principle equipment and technologies." And most importantly, the Academy must "strengthen the engineering aspect of its institutes."

This formula, based on nominal dedication to basic research and substantive measures to foster technological development, has been echoed by the president of the Academy, G. I. Marchuk. Marchuk conceded that the Academy and the universities have been excessively preoccupied with preproduction development of their research projects to the detriment of "fundamental science." But he claimed that at the same time he was obliged to broaden the network of research institutions with technical orientation in answer to the call of the Party Congress. Marchuk cited the new Department of Informatics, Computer Technology, and Automation as an example of the current trend toward engineering goals.[3]

The restructuring Program attempted to resolve the apparent contradiction between basic research and industrial innovation in the Academy by interpreting basic research not as a pursuit of science for its own sake, but as goal-oriented research leading to development of advanced technologies which critically depend on intensive theoretical and experimental groundwork. It is this critical dependence on massive R&D input, characteristic of advanced technologies, that forced the Soviets to push the Academy of Sciences toward technological innovation.

The Academy thus bears primary responsibility for originating and carrying through advanced technology development in the Soviet Union. However, in performing this function, the Academy is no longer wholly autonomous, but appears supervised to some extent by the State Committee for Science and Technology.

The Program has assigned a much stronger role to the State Committee than to the Academy in the overall management of the national R&D effort. Thus, the State Committee will determine priority areas of R&D, manage major scientific and technical interbranch task projects, monitor industrial R&D performance, assess the quality of Soviet products against world standards, and establish networks of R&D, project design, and technology organizations.

The effectiveness of the Academy of Sciences in discharging its responsibilities depends heavily on the way in which the Academy's achievements are translated into manufactured products. However, the organizational independence of the Academy system from the industrial ministries inhibits the Academy-industry interaction essential to the successful operation of the R&D process. The result is a break in the R&D cycle between the last stage performed by the Academy and remaining development work required for industrial production.

Academy writers stress the view that effective research requires a single organizational structure, a unified scientific-technological complex designed to minimize the effect of bureaucratic barriers, provided that, first, it must be broadly supported by a network of industrial-type facilities, and second, it must be operated by the Academy of Sciences.[2,35]

The main components of the unified complex would be industrial-type pilot plants specialized in the various areas of advanced technology, where they would smoothly mesh with the development stage of the R&D process. This structure would make it possible for the Academy to proceed beyond exploratory research and development to the point of finished experimental prototypes, and would eliminate the need of industrial ministries to repeat much of the Academy's research work.[2]

The Academy's demand for control of the scientific-industrial complexes is sure to invite a power struggle between the Academy and the industrial ministries. The Academy has no developed network of specialized pilot plants at this time. If placed in control of the R&D cycle, the Academy would have to procure the plants from industry. The industrial ministries would certainly resist a large-scale transfer of such assets to the Academy.

On the other hand, if the leadership of the R&D cycle in the advanced technology area were to be vested in the industry, the latter would have to acquire scientific talent from the Academy, which would oppose equally strongly any mass transfer of its scientists to industry.

It appears, therefore, that problems involved in the operation of the advanced-technology R&D cycle have deeper ramifications than the discontinuities due to administrative boundaries, and extend to the problem of control of the R&D process itself. These problems will have to be overcome if the Academy is to succeed in its most ambitious venture in advanced technology development—the reorganization of computer R&D.

THE INITIATIVE OF THE ACADEMY OF SCIENCES IN THE COMPUTER FIELD

In 1983, the USSR Academy of Sciences established a new top-level administrative unit in its table of organization: the Department of Informatics, Computer Technology, and Automation. Creation of the new department, involving the transfer of research institutes from other departments of the Academy, the founding of new institutes, and the planning of a complex network of research projects embracing the Academy and the computer industry, amounted to a major reorganization of the Academy of Sciences. Departmental changes have been rare in the Academy—the previous one of a similar nature occurred two decades earlier, involving the establishment of the Department of Mechanics and Control Processes.

From the perspective of restructuring, the reorganization made the Academy of Sciences the first component of Soviet R&D to take a major initiative dedicated exclusively to an area of advanced technology. Although it is not clear that the Academy's reorganization had been undertaken within the framework of the restructuring drive, the timing, scope, and purpose of the reorganization place it among the principal reform measures currently aimed at Soviet science and technology.

The reorganization is a response to the pressing national need to upgrade the ailing Soviet computer technology. Its weakness, a subject of vigorous discussion in both the Western and Soviet press, has been manifested by a substantial time-lag behind Western developments, and appears to involve the quality and quantity of practically the entire range of existing computer types and sizes, the rate of computer utilization, and the extent of computer literacy.⁴ Efforts to improve the situation during the past two decades were confined primarily to the computer industry; the 1983 reorganization marks the first time the Academy of Sciences has entered the field of computer technology as a

⁴Computer availability within the Academy, a prime candidate for computer support, is a striking example of these problems. According to A. A. Dorodnitsyn, director of the Moscow Computer Center of the Academy of Sciences, who for 20 years has been in charge of distributing computers among the Academy institutes, the present situation is the worst ever. Of the Academy's recent order for computers, only 26.1 percent of the YeS 10-66 computers and only 6.25 percent of the YeS 10-46 computers have been delivered, even though the latter could meet 75 to 80 percent of all the computation needs in one institute. Only one-half of previous Academy computer orders has been satisfied.[36]

Personal computers and copiers are still scarce at the Academy. Soviet data bases and computer centers using 100 megabyte disks fail to realize their full potential because the disks are unreliable. As of October 1986, the Institute of Scientific Information in Social Sciences, with a data base for 1400 collective and individual users, had but 12 personal computers.[37]

major player in an attempt to deal with the problem on a significant scale.

However, computer technology depends extensively on both scientific and industrial support and is thus highly vulnerable to the disfunction of the Soviet R&D process. If the Academy of Sciences assumes a major role in computer development, developers will be at risk of inheriting the Academy's problems of interfacing with industrial production. Furthermore, any gains the Academy may achieve in integrating the R&D cycle will be offset if the system fails to address the disincentives affecting the production organizations participating in the process.

The bleak picture of the Academy's technological developments has been moderated in the past by several positive factors. Not all technologies depend on the Academy-industry interaction to the same extent. For example, pulsed-power technology reached a high level of development in the hands of the Academy's institutes, partly because it did not require intensive industrial support. The end products of pulsed-power research were generally one-of-a-kind devices, however complex and large, that had been built mostly by the Academy's own resources. Here, the military may have enjoyed direct benefits, bypassing the Academy's handicaps.

Another moderating factor emerges from an entirely different dimension, involving a second paradox of the Soviet system: In the collectivist Soviet society, individual dedication and initiative often spell the difference between failure and success. There are several technologies whose success is directly traceable to extraordinary efforts of individuals, such as S. P. Korolev, who has been responsible for Soviet rocketry, I. V. Kurchatov for nuclear weapons, A. I. Mikoyan and M. I. Gurevich for fighter aircraft, B. Ye. Paton for electrowelding, and A. V. Gaponov for high-power microwave devices. One can surmise that, if the current attempts at economic reform succeed, they will be also largely due to the efforts of another dedicated and energetic individual, M. S. Gorbachev.

The attempt to energize the Soviet computer industry under the leadership of the Academy of Sciences, and the reorganization of the Academy carried out for this purpose, have been largely the initiative of yet another dedicated individual, Ye. P. Velikhov.

Velikhov has had a highly successful career since the 1970s, particularly as a promoter of pulsed power and concepts of interest to space defense. Notable are his 1974 paper on the application of underground thermonuclear explosions to drive magnetohydrodynamic (MHD) generators of very-high-current pulses, and his role in the development of transportable rocket-driven MHD generators for seismic exploration.

He is also known for his support of research on controlled fusion reactions, focusing on inertial confinement fusion reactors based on high-energy, high-current, charged-particle beams and high-energy laser beams. Another research project that attracted Velikhov's interest was crystal channeling of electron beams, with a potential for X-ray lasers.

In 1977 Velikhov became Vice-President of the Academy of Sciences, USSR, and a year later he was appointed board member of the State Committee for Science and Technology. In the early 1980s, Velikhov became directly involved in the problems of Soviet computer technology and began a campaign to create a new division in the Academy dedicated to computers.

Velikhov's campaign reached its goal in 1983, with the establishment of the Division of Informatics, Computer Technology, and Automation, and its approval by the Central Committee of the Party. Velikhov was made head of the new division, chairman of the Scientific Council for Complex Problem "Cybernetics," and leader of all computer development operations of the Academy of Sciences.

In view of Velikhov's long-standing dedication to directed energy, his recent initiative in computer development suggests that, in part at least, the Academy's reform is motivated by the prospect of competition with the United States in space defense where the weak position of the USSR in computer technology would be an intolerable disadvantage. To redress that disadvantage would require an all-out attack on the multiple problems impeding the development of Soviet computing capability. According to Velikhov, such is the scope of the current reorganization.

The symbol of this undertaking is the Soviet term "Informatics" in the name of the new Department, which covers areas associated with the development, creation, utilization, and servicing of information processing systems, including machines, equipment, software, and organizational aspects, as well as the complex of industrial, commercial, administrative, social, and political influences.⁵

Velikhov has announced that the basic mission of the Department of Informatics, Computer Technology, and Automation is to secure a scientific base "capable of eliminating in the shortest possible time the computer technology deficiency that threatens the development of the entire national economy." The immediate task is to develop and provide new computer technology in the deficient areas, or in what Velikhov calls the blank areas on the chart of Soviet computer technology.

⁵Velikhov defined informatics as the "Branch of national economy that includes electronic computer technology and electronic industry.[35] B. N. Naumov, the director of one of the new institutes of the Department, included both hardware and software in computer technology under this term.[38]

These are the supercomputers and their software, small efficient computers for mass use in research, design, and automation, and personal computers.[39]

The creation of the new Department has been accompanied by an extensive debate, which started about 1980 and continues to the present, regarding the role played by the Academy of Sciences and its relations with the industry in the computer field, and regarding the factors responsible for the present state of Soviet computer technology. The participants of the debate were Academy leaders, such as its former president, A. P. Aleksandrov, vice-president Velikhov, vice-president V. A. Koptug, G. K. Skryabin, chief scientific secretary of the Academy's Presidium, B. Ye. Paton, president of the Ukrainian Academy of Sciences, Yu. A. Osip'yan, director of the Institute of Solid-State Physics in Moscow, V. M. Tuchkevich, director of the Ioffe Physico-technical Institute, A. N. Skriskiy, director of the Institute of Nuclear Physics in Novosibirsk, and key members of the new Department, such as B. N. Naumov, director of the Institute of Informatics Problems, A. V. Rzhhanov, director of the Institute of Semiconductor Physics in Novosibirsk, and A. P. Yershov of the Novosibirsk Computer Center.

The speeches of these scientists and administrators, delivered mainly at the general meetings of the Academy of Sciences, and the articles published within the framework of the debate in the Academy's house organ, the *Vestnik Akademii Nauk*, provide considerable insight into the basic issues facing the Academy in the computer field.

Perhaps the most curious aspect of this debate is the number of references to a loss of computer research institutes that the Academy of Sciences has allegedly sustained in the past. These references omit, with one exception, the names of the lost institutes and the period in which the loss occurred.

According to Heather Campbell, "Information about computer research institutes transferred in 1963 or later is almost totally lacking. Most of the computer research institutes were transferred to the Ministry of Radio Industry." [40]

Alexandrov, Velikhov, and Koptug asserted that when the USSR began the development of computer technology, Academy institutes working in this area were transferred to other agencies. As a consequence, the Academy's computer research was largely discontinued, except for a few interested mathematics institutes.[41,42] Among the transferred institutes was the Institute of Precision Mechanics and Computing Technology (the developer of BESM-6), capable of carrying the R&D process to the point of prototype construction, and probably the Institute of Electronic Control Machines.[35] Campbell confirms

that the former was one of the institutes transferred from the then Department of Technical Sciences of the Academy. She also puts it under the joint control of the USSR Academy of Sciences and the Ministry of the Radio Industry.[40] Directories list the Precision Mechanics Institute under the Academy of Sciences, USSR, as late as 1985.[43]

Osip'yan attributed the inadequate development of Soviet computing technology to this loss and held that the industrial institutes which took over computer R&D from the Academy were unable to solve the problems of contemporary computing technology.[25]

At the same time, Velikhov and Koptug insisted that the Academy must now recreate the structure necessary to improve the present situation, i.e., regain the lost institutes, and organize its scientific technology base.[35,42] According to this viewpoint, no progress can be achieved without the Academy's development of the necessary theoretical and experimental research in solid-state physics, semiconductor physics, and radiophysics.[25] In Velikhov's words, "When the development of computers was in the hands of the Academy, operating in the context of a broad scientific interchange, things were much better than now, in spite of the fact that the number of workers engaged in computer technology is now much larger." [35]

According to Osip'yan, the "relative neglect" of the computer field by the Academy of Sciences, associated with the loss of institutes, changed into more active participation about 1980.[44] Prior to that time, even the existence of the Coordinating Committee on Computer Technology in the Academy of Sciences failed to compensate for the Academy's inaction. In 1981, Velikhov asked the Academy to become more involved in this problem.[27] Two years later, Velikhov again stated that the Academy must recreate the structure necessary to improve the present situation and to organize the scientific technology base.[35]

The past neglect of computer technology by the Academy was also discussed by Rzhhanov. In his account, the participation of the Academy in the development of microelectronics has been, until quite recently, limited to individual pieces of research either of purely theoretical interest or devoted to the solution of particular problems encountered in development. Rzhhanov attributed this to the unsatisfactory relations between the Academy and the computer industry, rather than to the loss of facilities.

Rzhhanov offered a comprehensive analysis of Soviet difficulties with the transfer of R&D results to industrial production. He stressed the serious organizational problems in long-range research projects that have been initiated and carried through early phases by fundamental

science and that require, for practical realization, the contribution from highly developed technology and extensive technological support. Thus, according to Rzhhanov, the results of research initiated from basic theoretical considerations, that turn out to have practical applications, either cannot be realized in practice at all or wind up as incomplete laboratory prototypes that cannot attract serious attention from industry. On the other hand, Academy research performed on contract with the industry is, as a rule, duplicated by industrial institutes because of the sharp difference in the technological support between the Academy and the industry. The cases in which design development is performed directly from Academy's results are rare exceptions.[2]

This viewpoint was supported by other participants of the debate. Complaints were made that too many ministries are working on the computer problem. Making computers is a profitable business, and no ministry wants to surrender its share of the project.[45] The organizations producing computer hardware and software are too diverse. Soviet computers are produced by as many as four ministries, and about 30 more ministries and agencies produce various computer accessories. Each industrial branch has its own technology policy and its own standards, which are not always compatible with the standards of other branches and with the needs of the users.[38]

A well-known complaint attributed the problems of Academy institutes in realizing the results of their research to industrial enterprises that adhere to innovation plans much less closely than they do to production plans.[46] Thus the industrial ministries, as a rule, focus on short-term problems at the expense of long-term research.⁶

The uncompromising dedication to the continuity of production on the part of the industrial ministries was said to hamper the conclusion of contracts between the Academy and the industry even in such nationally important areas as computer technology. This situation was particularly aggravating in the Siberian Department of the Academy of Sciences, where the share of industrial contract work was much higher.[42]

Another problem was the virtual monopoly that leading (*golounyye*) industrial research institutes have established over individual research

⁶The following case cited at the Academy debate provides a good example of the Academy-industry problems: The Institute of Solid-State Physics has developed the technology for producing sapphire tubes for street lighting. Their efficiency is such that if all illumination of Moscow were converted to these tubes, the electricity saved would be sufficient to light up Leningrad. The Institute proposed that the Ministry of Chemical Industry provide for the Academy a small plant to set up the production of the sapphire tubes. Although this plant was manufacturing obsolete equipment and had low productivity and poor working conditions, the Ministry refused the Institute's proposal, because nobody could take over the production plan of the plant.[25]

projects. Following this policy, the industrial institutes resisted accepting research results from off-line organizations, such as the Academy or *Vysshiye uchebnyye zavedeniya* (VUZ).[47]

Velikhov and his supporters regarded these policies of the computer industry as typical examples of bureaucratic interagency barriers and as a key factor inhibiting the development of Soviet computer technology.[35,48,49]

The Academy's position emerging from this debate can be summarized as follows:

- The Academy of Sciences should not be held responsible for the present unsatisfactory situation in Soviet computer technology, since it largely withdrew from the necessary R&D, following the loss of some of its institutes taken over by the industry.
- The industry that was in charge of computer R&D and production has been unable to equal the advanced standards of Western computer technology and has been beset by incompetence, shortsightedness, parochialism, and excessive diversity.
- The only way to improve Soviet computer technology is for the Academy to take overall charge of planning, coordination, and R&D in the computer field, reacquire its research institutes and facilities, and establish its own technological base, including pilot plants. These measures should be accompanied by a substantial increase in funding for the Academy.

The Academy's claims may not be entirely justified: The Academy of Sciences had not been as detached from computer R&D in the recent past as it now claims. Its Coordinating Committee on Computer Technology, chaired by G. I. Marchuk, was expected to direct the overall work of the program performed by the industry and by the Academy of Sciences.[35] The Scientific Council for Cybernetics, established in 1959 under the Presidium of the Academy of Sciences, has been active ever since [40].

It was also an exaggeration to say that the Academy's research in the computer field was largely discontinued, except for a few interested mathematics institutes, when significant work was being done for over two decades by the Glushkov Institute of Cybernetics in Kiev. Medium-size computers were built by the Armenian Academy of Sciences and other republican academies.[40] Elsewhere, Velikhov claimed that many Academy institutes have been performing research in computing technology for some time.⁷[50]

⁷There are many examples of this long-standing research. The annual reports of the Academy of Sciences, USSR, listing projects pursued by its institutes in 1980, included

On the other hand, since the inception of the Soviet computer industry, the *Minradioprom* and *Minpribor* have performed a major share of the R&D work.⁸ Production of computer hardware was controlled mainly by the two ministries.[40]

Nevertheless, these claims served as a strong argument in favor of the Academy's bid to solve the Soviet computer technology problem. More important to the Academy's claim for leadership was the indisputable fact that the Academy concentrated the top scientific personnel and possessed the necessary theoretical and experimental expertise in the computer field.

Most significant, however, was the Academy's argument that science, rather than industry, holds the key to the problems of Soviet computer technology.

In Velikhov's words,

A major cause of the present situation is that the solution of computer technology problems requires the most advanced basic research in many areas, research that is being performed by the Academy of Sciences. The revolution in electronics and computer technology is mainly due to micro-miniaturization which, in turn, requires a good understanding of solid-state physics and, in particular, surface physics. . . . Informatics, as a branch of national economy that includes electronic computer technology and the electronics industry . . . requires the establishment of special relations with science, or what we call science leadership; this is a subject to which the Academy of Sciences pays very close attention."[35]

The unique advantages of the Academy over industry have been emphasized by Rzhzanov and Osip'yan, who claimed that the majority of highly qualified Soviet specialists in mathematics, physics, and chemistry (which define the quality of microelectronics research) is concentrated in the Academy of Sciences system. On the other hand, the purely scientific capabilities of the industrial ministries are limited.[2.25]

Velikhov advanced two basic reasons why the new Department of the Academy has been established to take charge of computer development: The first was that many scientists active in computer

the development of LSI and VLSI technology using electron, X-ray, and ion lithography techniques, and the development of computer memory systems based on cylindrical magnetic domains and other submicron memory domains.[18] This work must have begun well before 1980. In 1981, Velikhov mentioned three institutes, FIAN, IRE, and the Leningrad FTI, doing important research in the physical principles of computer design.[27] In 1984, Academy of Sciences institutes were reported to have been working on robotics "for the past 15 years." [51]

⁸*Minpribor* is the Ministry of Instrument Construction, Automation Equipment, and Control Systems; *Minradioprom* is the Ministry of the Radio Industry.

technology have now been elected full and corresponding members of the Academy of Sciences. The second was his claim, noted above, that many Academy institutes have traditionally performed research in computer technology. Thus, according to Velikhov, the Academy had the main prerequisites to create the new Department: an existing base, a major mission, and scientific personnel which can join the Department without losing contact with other parts of the Academy.[35]

The mission of the new Department, concerned with solving the problems of Soviet computer technology "in the shortest possible time," involved several basic issues that demanded resolution if the mission were to be feasible. The most important by far was the issue of industrial utilization of the Academy's research results and the attendant problem of technological facilities that would bridge the R&D gap between the Academy and the industry. The second issue was the perceived need of a comprehensive national program for the development of computer technology. The third addressed the problem of technology transfer from the West. Each of these issues has been considered in the debate.

The first issue, concerning the interaction of basic and applied research with industrial production, was considered to be particularly acute in the case of microelectronics, acoustoelectronics, optoelectronics, integrated optics, lasers, etc. The novelty and complexity of the principles involved and the need to create special technology for research and for the transition to production were regarded as the principal factors preventing the participation of industrial institutes. Velikhov recognized the need for the intermediate technological support facilities—experimental production lines or pilot plants—that would serve as a bridge between R&D and industrial production.

At this time, the Academy of Sciences has an inadequate system of pilot plants, both in the quantitative and qualitative sense. According to Osip'yan, the number of such plants is insufficient not only to support the expected level of research of the Academy, but also to maintain its actual level. Furthermore, since the industrial wage system has been extended to the Academy, the pilot plants operate on the production quota system and do not readily support research.[44]

The establishment of adequate technological support at the Academy thus became a principal objective of its campaign. The plan was ambitious and broad in scope, calling for a well-developed experimental, design, and pilot production base capable of supporting all R&D stages, down to the design of technological and production processes.[1,35,48]

The second issue, concerning the lack of a unified national plan for computer development, was an important part of the Academy's rationale for assuming leadership in this area.

The planning, management, and organization of development, production, and use of computer technology have been carried out by a number of organizations such as Gosplan, the State Committee for Science and Technology, and the Main Statistical Administration, and by the main industrial producers of electronics technology represented by *Minpribor*, *Minradioprom*, and *Minelektronprom*.⁹ However, these organizations pursued no unified coherent, statewide program plan, and no single agency was appointed to take the entire responsibility for realizing such a program.[52]

Velikhov proposed that the Academy of Sciences, USSR, play the role of such an agency. The unified program, which would include mathematical methods and applied and system software, would then be a key element of the new Department's mission.[50]

Finally, technology transfer as a means of enhancing Soviet computer technology was rejected in favor of indigenous technology development that would make the Soviet Union equal to and independent of the West in this field. The Academy's belief was that computing technology should not be dependent on scientific and technical relations with other countries. Neither should simple technology transfers from foreign experience be expected to solve the national problem. It was stressed that no matter what modern specimens of foreign computer technology might be procured, the current worldwide state of the art precluded any improvement in Soviet technology level without the development of a native infrastructure.[25,48]

THE OUTLOOK FOR THE COMPUTER REFORM

The effort to reorganize the Academy of Sciences in the computer field appears to be the result of two factors: the perception that new and more effective measures are needed to improve the state of Soviet computer technology, and Velikhov's personal initiative. It is clear that computer technology has become the foundation of many new developments in industry and defense, and that Soviet deficiencies in the computer field may critically retard such developments in the USSR. The creation of a new department in the Academy of Sciences is a rare and important event in its own right; when dedicated to the computer problem, such an event assumes national importance. Thus, the Academy reorganization probably required the approval of the Politburo, the State Committee for Science and Technology, and the Presidium of the Academy of Sciences. Nevertheless, the published

⁹*Minelektronprom* is the Ministry of the Electronics Industry.

evidence indicates that the initiative to justify and launch the reorganization has come from Velikhov. It was Velikhov who set the tone of the reorganization debate, proposed the establishment of the new Department, defined its mission, and insisted on the broadest possible scope of its agenda.

Velikhov's leadership of this venture suggests that its direct purpose might have been more specific than the general needs of Soviet industry and defense for computer technology. In the past, Velikhov had not been particularly active in computer development. Instead, he is known for his enduring interest in exotic technologies, some of which, such as pulsed power and directed energy technology, are applicable to space defense. The latter, of course, critically depends on a vigorous development of computer technology. One would thus be justified in speculating that it was the consideration of Soviet space defense that prompted the reorganization of the Academy of Sciences. It is worth noting in this respect the fact that the Academy's decision to establish the new Department was practically simultaneous with President Reagan's speech on the Strategic Defense Initiative in 1983.

Velikhov's efforts were directed at both ends of the spectrum of computer technology—small computers and supercomputers—and at advanced chip fabrication methods. These technologies have been under industrial development for some time, albeit with indifferent results. The creation of new Academy research institutes dedicated to these technologies is, in itself, a severe indictment of the past industrial performance, and particularly of the industrial R&D.

Velikhov's diagnosis of the reasons for the poor results obtained by the Soviet computer industry was the same as that offered in the past by analysts of Soviet R&D in general: a lack of technological facilities and mechanisms for an orderly transition of basic and applied research results to the industry. His solution of the problem was to bring back the Academy to the computer field, provide such facilities and mechanisms, and place them under the control of the Academy.

In this, Velikhov followed Paton, the outstanding president of the Ukrainian Academy of Sciences, who has for years promoted similar views. In a recent speech, Paton said that "The main thing that scientists must ensure is that their R&D projects are carried far enough to accommodate the realistic potential of industrial enterprises to refine these projects and to launch them into series production. To do this, it is absolutely necessary that scientific establishments have a well-developed experimental, design, and production base." But Paton also added that "Much also depends on the attitude of industrial workers who must have a real interest in innovation, the ability and desire to undertake a justified risk, and courage not to shirk responsibility."

Velikhov skirted the issue of industrial incentives, partly because that would require a basic industrial reform, well beyond the purview of the Academy of Sciences. However, another reason appears to be the Academy's bid to control a major portion of the R&D cycle, including the key stages of development and prototype construction. Such control contradicts the practice of Western industry, where much of the R&D cycle and production are held under one administrative roof. This practice has been hailed by Soviet analysts as a basic cause of Western success; recall, for example, Rzhnev's praise of U.S. microelectronics, where "The organization of scientific research in large companies has avoided the gap between science and technology." The Soviet Academy's activists seem to overlook the fact that in the Western model it is an industrial roof that unifies R&D and production.

Instead of considering the merits of industrial incentives and industrial control of the R&D process, the Academy proposed to solve the problem of the "gap between science and technology" by resorting to various bridging structures, such as the science-production associations, interbranch science and technology complexes, and temporary laboratories, always to be held under the Academy's control. In this connection, the newly created State Committee on Computer Technology and Informatics may be helpful to the Academy by providing the needed authority from the top to coordinate the interaction between the Academy and the industrial participants of the research-production cycle.

The bridging structures have not operated effectively in the past because they failed to resolve the divergent interests of the participating Academy institutes and industrial enterprises. The Academy scientists resented being held accountable for the shortcomings of industrial workers, who still had to observe production quota schedules. There is no evidence to show that a better performance would be forthcoming from such structures in the computer field.

What can one expect from the Academy's bid to take over the leadership of the entire complex of computer R&D? From the American perspective, it would be as if Caltech and MIT were asked to bail out the Chrysler Corporation. Velikhov may share the drive and talent of Lee Iacocca, but he is in the wrong sector.

The weakness of Soviet computer technology is essentially an industrial problem and not a scientific one. Whereas the Soviets have the capability to keep abreast of new scientific and engineering developments, their pressing task is to translate these developments into reliable mass-production techniques and ultimately to increase both the quantity and quality of computer production. The solution to this

problem will have to be found within the industrial context. For this reason, the Soviets would do better if they placed the R&D process under industrial control, rather than vesting control in the Academy of Sciences. This, of course, implies the need for industrial reform to eliminate the deleterious effect of rigid production quotas and misplaced incentives. Equally important in such a case would be the need of a large-scale shift of scientific talent from the Academy to industry.

Short of these radical measures, the Soviet computer development program faces an uncertain future. Much depends on the efficiency of the Academy's links to industry and the degree to which Velikhov's requirements are met by Soviet leadership. There are two indicators to watch that may presage a moderate success in this venture: The first is evidence of a significant strengthening of the Academy's computer technology base. The second is evidence of actual measures taken to improve the incentive system and remove the rigid production quotas in the participating computer industry.

These relationships between science and industry are not unique to the computer field, but reflect the entire spectrum of Soviet high technologies in which the Academy of Sciences plays a major role. The same problems of transferring research results to industry are again traceable to the jurisdictional independence of the Academy from the production end of the R&D chain.

From the viewpoint of Western R&D organization, the Soviet Academy of Sciences appears as an anomalous phenomenon, without a counterpart in Western practice, which tends to distribute, rather than concentrate, scientific talent and to associate leading scientists with the industry without intervening organizational constraints.

While the Soviets are aware of the pitfalls inherent in their R&D system, they cannot, and probably do not wish to, change it to follow the Western model. To understand this, one must appreciate the Soviet stake in the Academy of Sciences as a priceless national resource and as the originator of technology. What could be regarded in a sense as a vice is turned into a virtue, and the very concentration of independent scientific capability is looked up to for solutions not only in matters of science, but also in problems of technology and industry itself.

In the long chain of measures undertaken to retain and bolster the existing system of Academy-industry cooperation, the latest is the establishment of the interbranch science and technology complexes. At a first glance, this measure does not appear to be qualitatively different from its predecessors, and it remains to be seen if it is capable of contributing materially to the progress of Soviet high technologies.

Thus, even if the Soviets succeed in significantly improving the performance of their computer R&D and production sectors, as a result of the concentrated efforts of Velikhov and other Academy leaders, they may still fail to close the high-technology gap because of the systemic problems affecting Soviet high technology as a whole.

V. THE BRIDGING STRUCTURES

The Soviet answer to the problem of industrial innovation manifested by the breach between R&D and production has been the organization of several types of administrative structures attempting to bridge the breach. Bridging structures predate considerably the innovation initiatives of the restructuring drive and represent primarily an organizational attempt at solution to the innovation problem. Although restructuring has now addressed the economic solution as well, postulating a series of economic incentives to make industrial production enterprises more receptive to R&D output, it has also involved further expansion of the bridging organizations.

Of the various possible remedies for technological stagnation, the Soviets have always exhibited a strong preference for the organizational approach. One reason for this preference is that creation of new organizations implies no qualitative changes of the system, whereas economic incentives, especially those mandating greater management autonomy and higher sensitivity to market forces, directly threaten the foundations of the Soviet economic establishment. Another reason is that the Soviets perceived the industrial innovation problem as mainly the result of organizational separation between R&D and production, so that organizational measures appeared as the logical and natural solution.

The earliest and most widespread bridging organizations are the science-production associations (NPOs¹) which combine industrial research institutes, design bureaus, pilot plants, and industrial production enterprises in a single administrative entity. The types of existing NPOs range from associations developing and producing single, unique pieces of equipment, to those engaged in mass production, and in large-scale innovation aid to industrial production plants. All NPOs are intended to bridge the "institutional separation of the creators of new technology" and ensure the "continuity of scientific and technical progress." [53] However, most NPOs are confined entirely to the industrial ministry system and do not include the elements chiefly responsible for the development of advanced technologies, such as the research institutes of the Academy of Sciences.

Bridging structures involving the Academy and dedicated specifically to the introduction of advanced technologies into industrial production

¹*Nauchno-proizvodstvennoye ob'yedineniye.*

have appeared much later than the NPOs and are represented by temporary laboratories, interagency and engineering centers, and most recently, the MNTKs.

Soviet literature is replete with discussions on the merits of bridging organizations as means for promoting technological development. However, much of it is approached from the viewpoint of traditional technology, which does not take into account the revolutionary nature and the specific needs of advanced technologies being developed by the Academy of Sciences. In particular, an often neglected but crucial aspect of such technologies is that their development depends on the ready availability of a rich base of supporting technologies, a multidisciplinary effort, and a high tolerance of risk. All three requirements are characteristically in short supply in the Soviet Union. The technology base is expected to fill out gradually as the various goals of restructuring are progressively reached. The beginning of true multidisciplinary development is taking place now in the unfolding MNTK network. But the risk-minimizing policy of Soviet management and the planned nature of Soviet economy may not be able to deal with technological risk.

A Soviet assessment of advanced technology problems that does take some of these factors into account was published in 1982 by A. V. Rzhanov, director of the Institute of Semiconductor Physics, Academy of Sciences, in Novosibirsk.[2] Although Rzhanov focused on microelectronics, his remarks are pertinent to the entire range of advanced technologies and bring out clearly the problems typical of such technologies.

Rzhanov begins by stressing that the interaction of the Academy's research with industrial production is a complex, multifaceted problem fraught with organizational difficulties. The novelty and complexity of microelectronics, acoustoelectronics, optoelectronics, integrated optics, and lasers, together with the need to create special support technology, demand that such interaction be carried out within a unified science-technology complex, including the Academy institutes and industry. Only such a complex can provide the necessary state of the art in the supporting technologies, such as chemical technology, materials processing, circuitry, lithography, and so forth. According to Rzhanov, the availability of these technologies totally determines the pace of research, the reliability of results, and often the feasibility of the research itself.

Rzhanov finds it is significant that the overwhelming majority of discoveries and inventions in microelectronics have been made in the United States, where the organization of scientific research in large companies and universities has avoided the gap between fundamental science and technology.

In the USSR, on the other hand, Rzhanov perceives the participation of fundamental science in the development of microelectronics as limited and hampered by the lack of a technology base in the Academy institutes. The inadequate technology base prevents the Academy from completing its research to the point of experimental prototypes, whose technical specifications would provide a realistic basis for assessing their practical applicability.

Since the majority of highly qualified Soviet specialists in mathematics, physics, and chemistry is concentrated in the Academy of Sciences system, Rzhanov argues that the Academy institutes should be the leaders of joint Academy-industry research and that the Academy should enrich its technology base by acquiring existing industrial research institutes and pilot plants.

Rzhanov's ideas about a continuous R&D cycle within an integrated organization dominated by the Academy and an adequate base of supporting technologies as preconditions for successful advanced technology development are reflected in the design principles of the various organizations set up to bridge the gap between R&D and production. In terms of jurisdictional control, these organizations range from complete domination by the Academy of Sciences, through mixed Academy-industry participation, to purely industrial associations. Since the latter, represented by the NPOs, are the oldest bridging organizations, there is clearly a discernible trend toward greater participation of the Academy, reflecting an increasing role of advanced technology in industrial development.

The Academy's involvement in the bridging organizations began in the 1980s when it established temporary laboratories and interagency and engineering centers, and set up some of the MNTKs. As part of the new policy, in December 1985 the Presidium of the Academy established the Scientific Council for Basic Problems of Promising Technologies, headed by the President of the Academy.

TEMPORARY LABORATORIES

In 1981, the State Committee for Science and Technology approved a proposal of the Academy of Sciences to set up a network of temporary scientific and technical laboratories within the Academy system.[54] The idea of temporary laboratories originated in the Presidium's Section of Physico-technical and Mathematical Sciences as a means of bringing its scientists closer to work on technological applications even at the cost of taking time away from basic research. The laboratories were to be established for a limited time in priority areas

requiring a sharp acceleration of research or promising considerable practical results. The State Committee would annually determine the number of such laboratories, based on proposals of the Academy, and initially approved 40 temporary laboratories.

The earliest and largest temporary laboratory was established at the Ioffe Physico-technical Institute in Leningrad, in the Division of Contact Phenomena in Semiconductors. The temporary laboratory was put in charge of developing fiber-optics communications lines, working on a contract financed by industry. The laboratory workers were granted considerable material incentives. The program was completed in three years and was considered a success.[55]

At the end of 1986, 31 temporary laboratories had been established, including one in the Siberian Department and four in republican academies; nine were being organized.[54]

INTERAGENCY AND ENGINEERING CENTERS

The concept of research centers operated by the Academy of Sciences as bridging organizations to facilitate and accelerate industrial innovation has been promoted by two agencies of the Academy: the Presidium's Section of Physico-technical and Mathematical Sciences led by Ye. P. Velikhov, vice-president of the Academy, and the Ukrainian Academy of Sciences, whose president is B. Ye. Paton. As noted above, the Section also initiated the temporary laboratories. Both Velikhov and Paton have been directing the installations and expansion of the centers and reporting on their progress.

Velikhov's 1986 report to the Presidium,[7] delivered well after the MNTK network had been established, does not mention the network, but describes the Industrial Lasers MNTK as one of the interagency centers of the Academy.² His Section has so far established five interagency centers in the fields of industrial lasers (the MNTK), automatic development of very large system integration (VLSI), development of systems for design automation, organization of mass production of personal computers and their software, and development of supercomputers. The VLSI center attached to the Cybernetics Council of the Academy of Sciences, USSR, is intended to unite Academy institutions with those of the radio and electronics industries.

²In view of Velikhov's policymaking position in the Soviet R&D establishment (vice-president of the Academy of Sciences and board member of the State Committee for Science and Technology), this omission introduces a degree of ambiguity to the status of the bridging organizations.

Four centers to study MHD generators, magnetic memory development, synchrotron radiation, and energy conservation are in the organization or proposal stages.

According to Velikhov, the interagency centers have been operating with varying degrees of success. The problem is the unclear status of the Academy and its rights concerning pilot production and industrial production based on its research results. The operation of the centers is also hampered by lack of supporting technologies, such as microprocessor technology for laser control or software for VLSI design.[7] All of Velikhov's operating centers are dedicated to the development of computer technology and represent the Academy's major effort to address this overall national problem.

The new types of bridging structures, such as the interagency and engineering centers and the MNTKs, have been modeled on the organizational initiatives of B. Ye. Paton at the Ukrainian Academy of Sciences. His past work to combine the research activities of the Ukrainian Academy's institutes with local industrial research and production enterprises has been the most successful example of cooperation between science and industry in the Soviet Union.

In the course of his work, Paton evolved the concepts of engineering centers and scientific and technical complexes (NTK³), the latter of which became the model for the MNTKs. Paton calls them new scientific institutional structures and a qualitatively new step toward the integration of science, technology, and production. In his view, the rapidly expanding goal-oriented basic research required the reorganization of science; in former conditions basic research and technological application of its results were far apart in time and in space. A number of the Ukrainian Academy's long time institutes performing goal-oriented basic research have essentially become large NTKs with their own design and technology bureaus, experimental production facilities, and pilot plants.

Paton notes four NTKs: Ye. O. Paton Institute of Electric Welding, which became the first MNTK, Institute of Materials Science Problems, Glushkov Institute of Cybernetics, and Institute of Super-hard Materials.

The engineering centers are problem-oriented organizations operating within the NTK network. They have been created specifically to deal with the problems posed by significant scientific ideas that cannot be applied in practice because of the lack of specialists in the industry, or lack of proper organization, or in cases involving several industrial sectors, where no single ministry wants to take responsibility for

³*Nauchno-tekhnicheskiy kompleks.*

introducing new technology. Using the results of basic research, the centers promote the development of new technologies, materials, and equipment, and facilitate their large-scale introduction into various branches of national economy.

The engineering center specifies the research, experimental design, start-up, and maintenance phases associated with the development of advanced technology, equipment, and materials, and their diffusion and effective production. Its specialists determine the areas and extent of application of large R&D projects and organize accelerated production of prototypes and trial production series, using their own or industrial facilities.

The centers use business accounting principles in dealing with production associations and industrial enterprises who are either their customers or manufacture the prototypes. The centers help overcome jurisdictional barriers, saving considerable time. By assuming the major part of the innovation work and retaining patent rights concerning that work, the centers take over much decisionmaking from the industrial ministries and are free to adapt the new technologies to the needs of particular industrial sectors. Their activity thus releases scientists from work on organizing innovation in the industry and provides stable feedback from industry to scientists.[16]

The centers described above are clearly the creatures of two leaders of the Academy system, Velikhov and Paton. Velikhov's interagency centers at the USSR Academy of Sciences and Paton's engineering centers at the Ukrainian Academy of Sciences represent unique institutions whose prospects for success are largely attributable to these two leaders. Of the two, Velikhov, as vice-president of the USSR Academy and frequent government spokesman for science and technology, is more visible and probably has more influence on top-level policymaking. The development of Soviet computer technology, the concern of Velikhov's interagency centers, is also a task of crucial importance to Soviet strategic and economic interests. However, Velikhov is primarily an Academy scientist with relatively little industrial management experience; since Soviet vulnerability in the computer field is more a matter of industrial than R&D shortcomings, Velikhov's distance from the industry may turn out to be a significant liability.

On the other hand, Paton's lesser national and international visibility is compensated by his extensive experience organizing effective cooperation between R&D and large industrial associations and enterprises. His ability to deal with and to overcome industrial resistance to innovation ensured success of the Ukrainian science and technology complexes. The latter, in turn, stimulated planners of the restructuring drive to launch the MNTK network. Paton's national influence

thus emanates from his tangible results, rather than from his position in the Soviet hierarchy. But Paton's impact on national technology development has been relatively modest, being focused mainly on metallurgy, and the Ukrainian achievements will be hard to emulate on a national scale without Paton's particular talents.

The potential for success of Velikhov's and Paton's organizations stems from the autonomy of the Academy of Sciences system, which provides a good measure of protection against some of the problems assailing R&D institutions within the industrial ministry system, as described in the following subsection.

SCIENCE-PRODUCTION ASSOCIATIONS (NPOS)

Elaborate bridges between R&D and industrial production are fairly common in the more traditional Soviet technology areas. These are the well-known science-production associations (NPO) linking research institutes of the industrial ministries, design bureaus, and industrial enterprises. They have been created in the past to overcome the bureaucratic barrier that exists within the industrial ministry system between industrial research and industrial production.

The industrial barrier accounts in some estimates for the current average period of 10 to 12 years from the start of development to the organization of serial production of new technology. The separate existence of industrial R&D and production also causes new technology to be developed in the R&D institutes and design bureaus without consideration of the actual capabilities of the production plants. Thus it often happens that when production of new technology is assigned to a manufacturing plant, it is easier to downgrade the new project to the plant's technological level than to bring the plant up to the level required by the new technology.[56]

The performance of NPOs has been indifferent, mainly because they have not been granted enough legal power to enforce efficient interaction among their constituent agencies. As a result, the majority of NPOs merely combined their science and production components administratively, without a thorough integration of their operations. The component institutions thus continue to exist separately within the NPOs, pursuing their own standard agendas and reflecting the same conflict of interest between research and production that affects the industry as a whole.[53] Many such associations are NPOs in name only. When an NPO includes mass-production plants, its scientific research institutes gradually lose their character, turning into an "appendage" of production. This happens because state plans treat

these NPOs as ordinary industrial enterprises and exclude such output indices as the scientific and technical level of production.[53,56]

Another obstacle to successful integration is inherent in the legal status of the NPOs. Their two main components, R&D and production, remain independent legal entities with their own systems of rewards and incentives. The R&D institutions fall into the state budget category of "Science and Science Service," controlled by the State Committee for Science and Technology, while production is the province of Gosplan.[56]

There are of course exceptions to this trend. Such is the nation's first NPO, the *Kriogenmash*, established in 1972 to develop and manufacture cryogenic equipment. It combined the industrial All-Union *Kislordmash* Research Institute with the Balashikhinskiy Plant under a common management and common party and labor union organization. According to its organizer, V. P. Belyakov, who bears the title of general designer of cryogenic technology, the *Kriogenmash* NPO has been successful because of the unified management, party, and labor structure and because it has achieved close cooperation between its scientists and production specialists. An important factor has also been a continuing effort of the institute to ensure the plant's readiness before it is assigned new technology for mass production.⁴[56]

A recent development, stemming from the success of the *Kriogenmash* NPO, is the creation of a kind of super NPO, the All-Union NPO (VNPO). The Ministry of Chemical Machine-building Industry (*Minkhim mash*) organized *Kriogentekhnika* (cryogenic technology) as the first VNPO, which absorbed all the NPOs and plants previously operating in the cryogenic field. The *Kriogenmash* NPO became the head organization of the VNPO. In addition, the latter absorbed the Odessa *Kislordmash* (oxygen machines) NPO, the Omsk *Mikrokriogenmash* NPO, which includes the Omsk plant for oxygen machine construction, the Moscow *Geliymash* (helium machines) NPO, and the Sverdlovsk plant for oxygen machine construction.[56]

Belyakov claims that the VNPO combines the advantages of all its components and eliminates the shortcomings they had when standing alone. The VNPO can address a broader range of tasks and pursue a

⁴The success of the *Kriogenmash* NPO must also be credited to the groundwork in cryogenic technology and in integrating science with industrial production laid by P. L. Kapitsa, an outstanding Soviet scientist. In the 1930s and 1940s, the Institute of Physics Problems of the Academy of Sciences under Kapitsa became the leader of cryogenic technology. Kapitsa then established the *Glavkislород*, an organization for the production of liquid oxygen that employed joint Academy and industrial facilities, an early prototype of the NPOs.[57] This venture was made possible by Kapitsa's drive and his remarkable engineering as well as scientific talent, personal attributes that appear to be indispensable for the task of uniting Soviet science with industry.

single technology policy in all plants manufacturing cryogenic equipment. Although it assumes a part of the ministry management function, the VNPO is primarily dedicated to ensuring world-level mass production.

VNPOs are being organized in several other industrial branches. But Belyakov questions whether the general designer and general director of the VNPO will have enough legal power to be effective. Although the Council of Ministers, USSR, has conferred broad rights on the general designers, they tend to be ignored by the industrial ministers. Belyakov regards the VNPOs as a favorable alternative to the MNTKs. However, the NPO system is for the most part internal to the industrial ministries, does not involve the Academy of Sciences institutes, and does not engage in the development of advanced technologies.

A comprehensive account of the NPOs has been recently published by K. P. Kedrova and other Soviet economists associated with the Academy of Sciences.[53] According to the authors, the potential of NPOs has not been realized in many ways because of organizational and economic problems. They give the following reasons for this failure:

1. Planning, financing, and economic incentives are not consistent because NPOs incorporate organizations financed from two different sectors of the national budget: "industry" (production) and "science and science service" (R&D). The interests of the two types of organizations are in direct conflict. The R&D organizations are interested first of all in the "introduction" of new technology, i.e., in starting production, regardless of its expected volume. The interests of industry, on the other hand, lie in meeting the production plan, growth in productivity, and other economic considerations. Consequently, industry is not interested in the introduction of technology that fails to show an obvious rise in production rates or a cost reduction in a given reporting period. As a result, the NPO falls victim to this conflict of interest and to further deterioration of the relations between R&D and industry.

2. The industrial ministries in charge of the NPOs violate the legal requirement to give priority to research and experimental design work over mass production of new technology. The NPOs refuse to let outside plants mass produce their technological output and therefore tend to overload their production capacities.

3. Although the NPOs were created to unify the R&D cycle that was fragmented among different organizations, the fragmentation remains within the NPO because the planning and financing of the different stages of the R&D cycle continues their separation. The

production plan quotas for NPO pilot plants interfere with the goals set by the R&D plan. Neither is the mechanism of funding R&D related to the economic incentives provided for NPO workers.

4. The system of economic indicators used in planning and evaluating the work of NPOs is essentially a direct copy of the industrial system with all the contradictions between current production goals and the long-range development needs. The NPO production output indicator does not take R&D into account, even though the latter represents a large share of NPO activity. As a result, the output indicator imposed on the NPOs forces them to maximize mass production and to minimize the development of new technology.

Kedrova's group of economists has few illusions about the ability of restructuring to improve NPO performance. They expect that even the use of profit as main performance indicator will fail to reflect the purpose of NPOs, since the pricing system makes it easier to show profit by boosting old production and increasing the prices of new products than by steady modernization of the production program. Neither will indicators of productivity growth stimulate NPO innovation, because innovation unavoidably incurs large labor and material expenditures.

To eliminate the pressure of production goals, in 1983 the Central Committee of the party and the Presidium of Ministers ordered an experimental transfer of entire NPOs in five industrial branches to "Science and Science Service" funding. But Kedrova comments that this transfer deprives the NPOs of their mass-production plants and thus of their only opportunity to master the industrial production process.

Many NPOs have failed to reach their objectives because of the lack of economic incentives, insufficient legal powers, and failure to enforce those powers. Although the basic NPO principle was integration of their component institutions, these NPOs achieved only administrative, but not operational, integration. Thus, the imposition of an NPO structure on a group of diverse organizations often became a matter more of form than of substance.

THE MNTK SYSTEM

The new MNTK system represents the first large-scale attempt to link the institutes of the Academy of Sciences and its advanced technology capability directly with industrial production. In their function of spanning science and industry, the MNTKs are similar to the NPOs. However, the "interbranch" designation in their name signifies that another key function is to span different industrial areas and

scientific research areas, thus affording a solution to the problem of interdisciplinary approach to the development of advanced technologies. To realize this bridging function, each MNTK, specializing in a stipulated advanced technology, embraces a number of institutions from the Academy of Sciences and from several ministries and other agencies.

The MNTKs also differ from the NPOs in their size and scope. A number of MNTKs include in their organization several NPOs and some of the largest industrial production enterprises of the USSR. The MNTK system thus appears as the most ambitious venture launched by the Soviets so far to solve the problem of industrial innovation, and is telling testimony to the importance of advanced technology in the perception of Soviet leadership.

Marchuk, the president of the Academy of Sciences, has been a voluble exponent of the merits of MNTKs. In his words, "The MNTKs are a new organizational and economic form of integrating science and production and of concentrating scientific, technical, and material resources on solving major technological problems and creating and introducing fundamentally new types of equipment and processes." [58]

The MNTKs are expected to coordinate and perform all R&D work in their area of technology from basic research to the construction of prototypes and beyond, refining the R&D projects with industrial participation to the point where they can be introduced into mass production. The MNTKs are also responsible for seeing that the technology they develop is widely disseminated throughout the industry.

Along with the primary drive to resolve the institutional barrier and interdisciplinary R&D problems, the MNTK system has been endowed with the power, at least on paper, to deal with some of the economic obstacles to technological development.

The most promising aspects of this power include the right to make additional requests for resources above the plan and to demand a quick response from the relevant supply agencies and ministries, priority in the establishment of pilot production bases, priority in ordering materials and resources, and the right to demand full delivery of the ordered amounts. [58] The MNTKs are also empowered to deal directly with any ministry and agency, to sell their production directly abroad, without middlemen, to earn hard currency, and to control the use of their profits. [59]

To implement the right to additional unplanned funding, the State Committee for Science and Technology established a reserve fund for additional MNTK financing and manpower. [58]

The MNTKs were also given the right to formulate proposals for the state Five-Year Plans in their areas of activity, and the right to establish direct scientific, technical, and production relations with CMEA (Council for Mutual Economic Assistance) member countries.

The Council of Ministries controls the organization of the MNTKs. It appoints the general director of each MNTK and approves the list of the organizations which are part of the MNTK. Each MNTK is led by a so-called "head institution," usually, but not necessarily, represented by a major research institute of the Academy of Sciences. The head institution is administratively superior to all other participating organizations, regardless of their affiliation. As a rule, the director of the head institution of the MNTK becomes its general director. Each MNTK establishes a council whose decisions are supposed to be binding on all organizations participating in the MNTK.

The MNTK system, as outlined above, would force the Academy of Sciences to participate in the industrial process to a considerable extent. In this situation, the Academy leadership has had to exercise great care in balancing the requirements of government and industry against the expectations of its own constituency, which viewed the pursuit of science as its primary mission. Having set off on the path away from basic research and its privileges, the important consideration was to preserve the integrity and augment the power of the Academy. In the design of the MNTKs, this meant maximizing industrial resources under the Academy's jurisdiction. As stated by A. P. Aleksandrov, the former president of the Academy, "The organization of the MNTK system was a difficult task. We had initially expected that a large number of industrial production enterprises would be transferred to the Academy of Sciences. . . . It became clear, however, that such a transfer will create considerable friction between the Academy and industry." [60] Thus, the present form of the MNTK system is a compromise between the Academy's and industry's desires.

To reassure the ranks of the Academy who favor its former position and independence and who are less than willing to go along with its current industrial involvement, Marchuk, the new president, went out of his way to stress the importance of basic research to the Academy. At the same time, he said that the restructuring drive sharply increased the responsibility of industrial science (as distinct from Academy science) for the results of innovation and for new technologies. [60]

But the Politburo's Ye. K. Ligachev had a different outlook: "The Central Committee has recently considered the problems [of unjustified

delays in the organization of MNTKs⁵). The directors of MNTKs, and the leaders of ministries, agencies, and the Academy of Sciences, are warned that they are personally responsible for effective utilization of this new-in-principle form of integrating science and production.”[53]

The restructuring travails that affect the Academy of Sciences as a whole do not seem to be a problem to B. Ye. Paton, president of the Ukrainian Academy of Sciences, who originated the MNTKs. In the Ukrainian SSR, Paton has been the most successful organizer of past Soviet efforts to integrate science and industry and has created an effective network of associations and programs linking the Ukrainian Academy to local industrial enterprises. One of his early integration efforts was the establishment of scientific-technical complexes consisting of the Ukrainian Academy institutes, design bureaus, and pilot and production plants. In 1977, these complexes were said to employ 22,000 workers. Paton has a profound understanding of the problems affecting Soviet industrial innovation and, particularly, of the role played by the fragmented R&D process.[23] In the current restructuring effort, Paton's Institute of Electric Welding has become the first MNTK.

Paton's success may be partly due to his broad use of the party apparatus in the effort to integrate science and industry. As he put it: “When many industrial enterprises and construction organizations are under the jurisdiction of union ministries, only party influence makes it possible to overcome departmental barriers. The work of the Ukrainian Academy's Western Science Center led by the Lvov *obkom* [party district committee] has demonstrated that this influence is highly effective.”[61]

In his book on the Soviet Academy of Science,[62] Stephen Fortescue appreciated Paton's emphasis on cooperation with the party, noting that the Presidium of the Ukrainian Academy has signed contracts with all the party *obkomy* of the republic and the Kiev *gorkom* (city party committee), and that these contracts cover scientific research work within the boundaries of the regions. According to Fortescue, Paton gave credit for the idea and implementation of the interbranch associations to the *obkom*, which also drew up the plans and confirmed the management personnel of the associations.

Paton's effective use of the party on the local, or even the republican, level to further his policies could perhaps be emulated elsewhere

⁵Aleksandrov admitted that problems with the organization of MNTKs are partly his own fault. The main phase of organizing the MNTKs coincided with the Chernobyl disaster, which diverted Aleksandrov, a specialist in atomic energy, from devoting enough time to the MNTKs.[60]

on the same levels to promote the MNTKs. But such a course is not a matter of policy to be promulgated and followed throughout a system; instead, it is the result of the personal drive and initiative of outstanding individuals.

THE DISTRIBUTION AND TECHNOLOGIES OF MNTKS

According to the State Plan for Economic and Social Development of the USSR, the MNTK system is designated as the primary developer of advanced technologies. In their speeches to the Supreme Soviet of the USSR, Marchuk and N. V. Talyzin, chairman of Gosplan, provided a list of new-in-principle technologies envisaged in the Plan for 1987. The list breaks down into four main areas: complex automation of production, advanced process technologies, biotechnology and medicine, and agriculture technology.

Complex automation of production depends on computer and automation technology, in which three areas are singled out: large computer systems, personal computers, and microprocessors.

Among advanced process technologies, the Plan specifies materials processing based on plasma, radiation, laser, and pulse technologies, welding, powder metallurgy, membrane technologies in chemistry, processes using ultrasound and high pressures, effective processes of complex raw material treatment, and increasing the yield of gas and oil deposits.[63,64]

The specialized areas of the MNTKs reported in the press correspond closely to the technology areas specified in the Plan, down to such idiosyncratic topics as membrane technology for the chemical industry and pulse machines. Table 1 lists the reported MNTKs by technology branch, name, and jurisdiction. The distribution by technology branch is the author's.

One should not assume that all the MNTKs listed in Table 1 are in full operation at this time. All appear to have been approved by the Council of Ministers, but the manner in which material on each MNTK has been reported suggests a wide variation in their organizational and operational status. In general, it is reasonable to assume that the amount of detailed information on a given MNTK is roughly proportional to its degree of completion. For that reason, the four MNTKs in Table 1 with the notation "no data" (no information other than their names) can be considered to exist only in the planning stage.⁶

⁶An alternative interpretation can be made that lack of information on a MNTK is due to sensitivity classification. This possibility is discussed in the Conclusions.

Table 1
REPORTED MNTKS

MNTK	Principal Jurisdiction	References
COMPUTERS AND AUTOMATION		
<i>Personal'nyye EVM</i> (Personal Computers)	Academy of Sciences, USSR	58,66,83
<i>Robot</i> (Automated Control Systems)	Industry	65,66
<i>Avtomatika</i> (Computer-aided Automation)	No data	66
ELECTRON-OPTICS AND SCIENTIFIC INSTRUMENTS		
<i>Tekhnologicheskiye lazery</i> (Industrial Lasers)	Academy of Sciences, USSR and industry	58,66
<i>Nauchnyye Pribory</i> (Scientific Instruments)	Academy of Sciences, USSR	79
<i>Svetovod</i> (Light Conduit)	Academy of Sciences, USSR	66
<i>Mikrofotoelektronika</i> (Miniaturized Electron-optics Sensors)	No data	66
<i>Radiatsiya</i> (Radiation)	No data	66
METALLURGY		
<i>Institut Elektrosvarki</i> <i>im. Ye. O. Paton</i> (Paton Institute of Electric Welding)	Academy of Sciences, UkrSSR	58,66,70,93
<i>Metallurgmash</i> (Metallurgy Machinery)	Industry	58,66
<i>Poroshkovaya metallurgiya</i> (Powder Metallurgy)	Academy of Sciences, UkrSSR	66,93
MACHINE BUILDING		
<i>Rotor</i> (Automated Conveyor Lines)	Industry	66,69,94
<i>Mekhanobr</i> (Advanced Crushing and Pulverizing)	Industry	58,66
<i>Nadezhnost' mashin</i> (Machine Reliability)	Academy of Sciences, USSR	58,67
<i>Impul'snyye mashiny</i> (Pulse Machines)	No data	66

Table 1—continued

MNTK	Principal Jurisdiction	References
CHEMICAL INDUSTRY		
<i>Katalizator</i> (Catalyst)	Academy of Sciences, USSR	66,68
<i>Antikor</i> (Anticorrosion)	GKNT	58,66,85
<i>Termosintez</i> (Thermosynthesis)	Academy of Sciences, USSR	66,83
<i>Membrany</i> (Membrane Technology)	Industry	58,66
PETROLEUM INDUSTRY		
<i>Nefteotdacha</i> (Oil Extraction)	Industry	58,66,85
BIOTECHNOLOGY AND MEDICINE		
<i>Biogen</i>	Academy of Sciences, USSR	58,66
<i>Latbiotekh</i> (Latvian Biotechnology)	Academy of Sciences, LatSSR	84
<i>Mikrokhirurgiya glaza</i> (Eye Microsurgery)	RSFSR Ministry of Health	59,66

NOTE: The available details on each MNTK are given in App. B.

It is useful to consider the jurisdictional and technological breakdown of Table 1 in the light of the avowed Soviet drive to install the MNTK system as the key tool to integrate the Academy's science with industry and so to assure the successful development of advanced technologies. For this purpose, the numbers of MNTKs in this breakdown have been summarized in Table 2.

Several facts emerge from this breakdown. First, the Academy of Sciences is not in charge of every MNTK. At least six MNTKs are directly under industrial jurisdiction and may not include any Academy institutes. Thus, the leading-edge research, as practiced by the Academy of Sciences, is not represented in over a third of the reported MNTKs. Second, the technological distribution seems directed more toward improving the existing processes and machines than toward developing advanced materials and devices. For example, one-half of the MNTKs are concentrated in metallurgy, machine building, and the chemical and petroleum industries, where the primary emphasis is on achieving higher reliability and efficiency of existing systems. No MNTKs have been established, so far in electronics, to develop composite materials or to promote the replacement of metal structures,

Table 2

MNTK DISTRIBUTION BY JURISDICTION AND TECHNOLOGY

Industrial Branch	Principal Jurisdiction					Total
	Academy of Sciences	GKNT	Industry	Health Ministry	No Data	
Computers and automation	1		1		1	3
Electron-optics and scientific instruments	3				2	5
Metallurgy	2		1			3
Machine building	1		2		1	4
Chemical industry	2	1	1			4
Petroleum industry			1			1
Biotechnology and medicine	2			1		3
Total	11	1	6	1	4	23

such as pipelines, with plastics. Third, the computer and electron-optics technologies appear underrepresented, in view of their importance to modern industry and defense, and their severe scarcity in the USSR. Computer technology is represented only by a single MNTK, and that is dedicated more to the production of an existing scarce commodity than to the development of new technologies.

The single MNTK in the computer field represents the only shortfall from the State Plan: For computer and automation technology, the Plan specifies large computer systems, personal computers, and microprocessors. Two of these—large computer systems and microprocessors—are missing from the MNTK network.

On the other hand, all three are represented in the new agenda of the Academy of Sciences and the system of linkages between the Academy and industry, discussed in the preceding section. The Academy-industry computer organization closely parallels the structure of the MNTKs and, through the Personal Computers MNTK, participates in the MNTK network. This complex relationship of newly emerging bureaucracies is already showing signs of potential conflict.

Ye. P. Velikhov, vice-president of the Academy of Sciences, in his 1986 report to the Presidium of the Academy, provided a strong, if indirect, indication of his opposition to the MNTK concept in favor of what he calls "interagency centers to accelerate the introduction of

[the] Academy's projects into production," to be controlled exclusively by the Academy of Sciences. According to Velikhov, the Physico-technical and Mathematical Sciences Section of the Presidium of the Academy of Sciences has already established several such centers, which are now operating with "varying degrees of success." [7]

In a detailed description of the existing and proposed centers, Velikhov carefully avoided any mention of the MNTK organization, although two centers (Personal Computers and Industrial Lasers) are in operation as MNTKs. The Scientific Research Center for Industrial Lasers (the first on Velikhov's list) is the head organization of the Industrial Lasers MNTK. While the Academy shares jurisdiction over this MNTK with the Ministry of Electro-technical Industry, Velikhov failed to acknowledge this fact, merely noting that the Academy should set up a close linkage to this Ministry, which should organize mass production of the laser systems. Furthermore, Velikhov said that according to an agreement with the Ministry of Electro-technical Industry, the Center (not the MNTK) will be assigned a manufacturing plant for series production of industrial lasers.

Velikhov also noted the existence of three other centers at the Academy of Sciences: Center for development of VLSI, Center for the development of systems automating design work, and Center for supercomputers. These centers probably fill the elements of the State Plan agenda that were missed by the MNTKs.

The conflict apparent in Velikhov's report on the interagency centers may thus be responsible for the absence of some advanced technologies from the MNTK network. Velikhov's attitude may be traced to the still unresolved question of the limits of the Academy's authority over the R&D stages beyond basic and applied research. This question is further compounded by the uncertain status of the MNTKs. The problems arising out of this situation are explored below.

The computer and electron-optics technologies show the highest proportion of MNTKs marked "no data." If our assumption about the meaning of this designation is correct, four of the eight MNTKs in these categories exist only on paper. This further strengthens the impression that, in terms of technological innovation, the drive behind the MNTK system is turning out to be much more conservative than Soviet planners would have us believe. On the other hand, these technologies have a particularly high military significance. The absence of published information may mean that the four MNTKs are operational, but have a military orientation and are classified.

The above technological limitations do not extend to other dimensions of the MNTK system. The extraordinarily ambitious scope of

this system becomes apparent whether one considers the sheer size of the MNTKs, their expected production plans, or the extent of their industrial involvement. The feeling of size of the MNTKs is conveyed by the following examples:

- The Advanced Crushing and Pulverizing MNTK will include 10 industrial branch scientific research institutes, 10 Academy and VUZ institutes, and the giant industrial combines *Uralmash* and *Novokramatorskiy Mashinostroitel'nyy Zavod*, in addition to other production associations.[66]
- The Machine Reliability MNTK will embrace the Institute of Superplasticity of Metals and the Control Design Bureau of Unique Instrument Building, the *Spektr*, *Burevestnik*, and *Tochmashpribor* NPOs, the Central Steam Boiler and Turbine Institute, and the *Vibropribor* and *Tenzopribor* plants.[67]
- The Biogen MNTK includes the Latvian *Bislar* NPO, the Special Design Bureau of Biological Instrument Making in Pushchino, six institutes of chemistry, molecular biology, biochemistry, genetics, and plant physiology, and the Main Botanical Garden in Moscow.[67]
- The Eye Microsurgery MNTK will include experimental plants and 12 branches throughout the USSR.[59]
- The projected production share of the MNTKs is similarly ambitious. The Scientific Instruments MNTK is slated to build one-third of the total national requirement for scientific precision instruments by 1990. The MNTK's share should reach 100 million rubles.[30] The Catalyst MNTK is expected to produce 80 percent of the new catalysts scheduled for development in the 12th Five-Year Plan by the ministries of the chemical, petrochemical, and fertilizer industries.[68]

The MNTKs weave a wide-ranging network of linkages across industrial branches and diverse industrial ministries. Thus, the Personal Computers MNTK is expected to deal with four ministries in computer development and 30 ministries in manufacturing parts and materials.[66] The Rotor MNTK includes 29 participating organizations belonging to 22 ministries.[69] The Paton Institute of Electric Welding MNTK operates enterprises of five all-union ministries.[58,70]

The size and structure of the MNTKs together with their new economic privileges provide a strong potential to resolve the perennial problems of Soviet advanced technology. But these resources have been described so far only in terms of plans, government decrees, and

administrative actions. As is often the case in Soviet affairs, there is a wide gap between legislated intentions and actual practice.

THE SIGNIFICANCE AND POTENTIAL OF THE MNTK NETWORK

The MNTK system is clearly intended by the highest levels of Soviet leadership to be the principal means of achieving advanced technology development. This is evident from the simultaneous application of three key measures, unprecedented in Soviet industrial policy: first, the massive engagement of the research institutes of the Academy of Sciences, the primary developer of advanced technologies, in joint association with industrial organizations; second, the size and scope of the individual MNTKs, which exceed those of the industrial NPOs; and third, the extensive management and fiscal policy powers granted to the MNTKs, which go far beyond those granted in the past to the NPOs.

The MNTK system addresses the institutional barrier problem in two dimensions at once: by integrating under one organizational roof both the entire research-to-production cycle and the different subject areas of research and branches of industry that are needed to develop a given technology. This double integration effort also provides the opportunity to redress the imbalance between science and industry—the scarcity of technological support in the Academy, and scarcity of scientific expertise in the industrial ministries.

Perhaps the most significant of the new fiscal privileges of the MNTKs is the power to change the approved resource allocations plan in mid-course. The right to demand, and obtain, additional resources above planned levels can go a long way toward making the system more responsive to changing circumstances typical of the development of advanced technologies.

The MNTK structure, armed with its economic rights and privileges, is expected to overcome the entire complex of Soviet problems with industrial innovation: economic disincentives, jurisdictional barriers, and operational misallocation of resources. This task is much more difficult for the MNTKs than for the industrial NPOs, if only because the bureaucratic barrier between the Academy of Sciences and industry is more formidable than any such barriers that may exist within the industrial system.

The charter of the MNTKs appears to reflect greater scope and more extensive rights than those granted the NPOs. But the question remains whether the MNTKs will fare any better. At this time, one-

and-a-half years after the empowering resolution of the Council of Ministers, the returns from the field suggest that the answer is largely negative. The complaints from MNTK directors, managers of their industrial components, and participating scientists strongly echo former responses to the NPOs: MNTK rights are not being enforced and they do not go far enough. Key problems are the still ambiguous legal status of the MNTKs, continuing organizational fragmentation of the R&D cycle, lack of unified wage and incentive standards, and the reluctance of Gosplan and the State Committee for Science and Technology to reflect the MNTK objectives in the state plans. The last point nullifies many of the economic rights of the MNTKs since, according to Golubev, contractual obligations can be enforced only in connection with activities approved in the state plans.

The MNTKs also appear to suffer in an area central to their basic concept—the interface between advanced scientific research and the existing industrial capability. Rather than to build new specialized plants for the MNTKs, industrial facilities engaged in the manufacture of traditional products have been diverted to serve the Academy's institutes. The traditional methods of these facilities and the skills of their personnel are not ready to meet the standards of quality and precision required by the new technology.

This problem reveals a fundamental weakness of Soviet leadership: the failure to understand the revolutionary nature of advanced technology. The latter is incompatible with the conservatism, parochialism, and incremental advance characteristic of traditional Soviet industrial practices, and calls for much greater emphasis on R&D, tolerance of risk, uninhibited flow of information, and, in the words of one Soviet critic of the reform, "an entirely different psychology and ideology of production."

The conservative bias of the Soviet leadership is also apparent in the spectrum of scientific and technological profiles assigned to the new MNTKs. The tendency to upgrade traditional technologies, rather than develop and produce new ones, can be deduced from the fact that over one-third of all MNTKs are not led by the Academy of Sciences, the heavy concentration of MNTKs in metallurgy, machine building, and petroleum industries, and the poor coverage or absence of MNTKs in areas where the Soviet Union is particularly weak—computer technology, electronics, plastics, and composite materials.

It can be argued that the topical conservatism of the MNTK system reflects the economic disparity between the East and the West. The sustained demand of Western societies for ever more advanced information, communications, transport, entertainment, and other services and goods has no comparable equivalent in the Soviet Union. As a

result, the MNTKs represent what Soviet leadership considers as technologies appropriate to the present level of development of Soviet society.

This argument would assume that the MNTK network has been intended mainly to serve the needs of the civilian sector of the Soviet economy. But an equally important purpose is the establishment of a strong advanced technology base to drive further developments of value to both the civilian and the military sectors. Although the Soviet military procurement system has been quite effective in traditional technologies, the advanced technology problem is nationwide, as has been amply demonstrated by the situation prevailing in the computer field. Progress in advanced technology for the military also depends on a well integrated science and industry system. Since the MNTKs represent the currently favored means of such integration, it is possible to conjecture that some MNTKs are dedicated to the military. Their lower visibility in the Soviet press could then account for the lack of data on the *Mikrofotelektronika* (miniaturized electron-optics sensors), *Svetovod* (light conduit), and *Radiatsiya* (radiation) MNTKs.

In their present early period, the MNTKs seem to be failing in all three main categories of innovation problems—economic, organizational, and operational. Of the three, the most damaging is the economic factor because it means that industry has no real incentives to introduce new technologies, the mainspring of innovation. However, the establishment of such incentives probably involves a deeper restructuring of the Soviet economy than what Soviet leadership is prepared to attempt.

The disappointing record of the Soviet struggle with innovation has had some exceptions. One is the *Kriogenmash* NPO. But its success can be attributed to the efforts of Belyakov, its organizer, and Kaptisa, the founder of cryogenic technology, rather than to the merits of the NPO system. In a similar way, Paton's MNTK will probably live up to its promise, thanks to Paton's experience, understanding of the problems, and ability to manipulate the levers of power. It is a big question if the effectiveness of talented individuals can be transposed from a local to a national level, involving the entire MNTK network.

The MNTK concept has its detractors and competitors within the Soviet R&D establishment. In the Academy of Sciences, Velikhov is advocating and expanding the network of interagency centers with similar objectives to the MNTKs, but to be controlled exclusively by the Academy. Although some of these centers are actually participating in the MNTKs, Velikhov studiously avoids any reference to the latter. In industry, Belyakov has been successfully promoting the VNPOs (all-union science-production associations), which he regards

as a favorable alternative to the MNTKs. The establishment of the Academy's interagency centers and the industrial VNPOs appears to be totally uncoordinated with the MNTK drive, giving the impression of chaotic planning and management at the top.

At this time, the Central Committee regards the MNTK as the preferred system. Its expansion demonstrates an earnest effort of the Soviet leadership to solve the problem of introducing the results of scientific research into industrial production. But the urgency of this effort is reflected only in the speed with which the MNTKs were set up, amounting to better than one MNTK per month, and in the desire of the Central Committee to shorten the organizational period. Once the MNTKs have been established, the further steps necessary to ensure their viability, such as procurement of facilities, resources, and the all-important economic powers, appear to have been mired in the usual bureaucratic process.

In the judgment of Soviet observers, the outlook for the MNTK network as the principal instrument of redressing Soviet imbalance in advanced technologies is not encouraging. Bureaucratic resistance coupled with the unprecedented complexity of the new organizations may doom them to the fate of the NPOs. The difference is that now the future of advanced technologies is in question, affecting Soviet capability for technological and military competition with the West.

One can conclude that the specialized organizational structures that the Soviets have been devising in ever increasing complexity to solve their industrial technology problems are not likely to do their job within the present economic system. The current restructuring drive offers the promise to change at least the worst aspects of that system. Along with other components of Soviet science and industry, the MNTKs have much to gain, particularly from the new openness (*glasnost*), since the free flow of information is a critical prerequisite to the development of advanced technology. But the success of the MNTKs, should it occur, on the heels of a successful restructuring drive, would flow from the generic improvement of Soviet industrial relations rather than from the particular organizational features and privileges of the MNTK network.

VI. REFORM RESULTS

Complaints about innovation have been a constant feature of Soviet economic and technical assessments of their industrial performance. Through the years, this pattern of criticism has shown two recurring themes: economic disincentives and absence of an intermediate mechanism between R&D and production that would facilitate the innovation process. Prior to the current reform effort, Soviet planners largely neglected the first and concentrated on the second theme, envisaging such a mechanism in the science-production associations (NFOs). The restructuring drive now proposes to deal with both themes, devising various incentives through economic reform and establishing ever larger bridging organizations (VNPOs, MNTKs, etc.)

A year after the approval of the restructuring reform by the 27th Party Congress, the process of implementing the reform throughout the Soviet economy appears to be failing to meet most expectations. Criticism of the implementation is being voiced by a wide range of Soviet experts, from economists and industrial managers to scientists and research directors of the Academy of Sciences. Their assessments reveal concern with several distinct issues at the root of the implementation process: the response of bureaucracy managing the national economy, the role of the regulatory mechanism, the progress of decentralization, and, what is most important from the viewpoint of advanced technology development, the problems of industrial innovation. A good illustration of the combined effect of these issues is the assessment of the MNTK network and its activities. The following subsections discuss each of these issues in turn.

STRUCTURING AND MANAGEMENT OF THE NATIONAL ECONOMY

In the opinion of Soviet scientists, the most damaging obstacle to the implementation process is the breach between management of the technological modernization drive, on the one hand, and management of national economy, on the other. The latter continues to be based on quantitative cost indicators of production growth and does not take into account the quality of production, efficiency of resource use, and the effect of prices. Under these conditions, a comprehensive approach to modernization and the development of interbranch and interregional relations are found to be inconvenient for enterprises and the industry.[71]

This finding was officially conceded at the June 1987 meeting of the Central Committee, chaired by Gorbachev. N. N. Slyun'kov, secretary of the Central Committee, stated that the economy continued to operate according to the traditional expenditure-oriented mechanism, which retains gross production indices. This mechanism tends naturally to increase expenditures because expenditures increase production. This in turn creates scarcities in the economy, because production does not follow demand and consumers have no choice of products. As a result, the economy generates unwanted and often poor quality products. Enormous subsidies and credit defaults, low credit interest, and the existing pricing structure all reward inefficient resource utilization.[72]

The scientists also criticized the absence of a systems approach to the technological modernization of production. Thus a technological novelty becomes the basis of productivity growth only in conjunction with appropriate changes in the structure and organization of production.[71]

The failure to implement such changes has been pointed out by B. Ye. Paton, a leading activist of the restructuring drive. Paton claims that the necessary internal organization of the participating institutions and inter-institutional linkages between science and production has not yet been attempted. Neither have the authorities established any mechanism linking the internal plans of organizations and the national Five-Year Plans with the Complex Program of Scientific and Technological Progress of CEMA Members up to the Year 2000.[73]

A similar lack of integration with national planning objectives arises in the case of the Academy of Sciences. Although the Academy has made a considerable theoretical contribution to economic problems of scientific and technological progress and to the improvement of national economy management, an effective relationship with the planning organs of the state has not yet been established.[74]

The scientific councils of the Academy of Sciences have so far failed to achieve authoritative status in their function of coordinating inter-branch industrial research. There has been no feedback from industry on their advice. The councils have no legal rights to include proposed research projects in the national plan, and cannot participate in funding decisions.[75] One observer concluded that restructuring has only weakly affected the problem of introducing the Academy's research results into the national economy.[76]

An early reaction of the NPOs to the resolution on self-supporting operation of R&D establishments was voiced at a discussion among NPO managers moderated by a representative from GKNT. The discussion covered many of the key problems involved in the transition to

a self-supporting mode: the mechanism of price setting and taxation, conflict between planned and contractual work, and the new challenge of independence.[77]

Three basic points became clear at the outset. First, the R&D establishments have still some leeway for temporizing and are not forced to adopt the new system immediately. Second, not all of the establishments are in favor of the new system. And third, one of the most important features of the reform, control of profit, is not left entirely to the discretion of the recipient, but is subject to regulations.

The uncertainty about price setting and taxes has delayed industrial users of R&D in responding to contract proposals. The users have no way of assessing their available resources to find out if they can afford the prices. The scientists complained that there was no mechanism for determining prices in the science sector. On the other hand, GKNT pointed out that the establishment of such a mechanism would violate the purpose of free negotiation. Prices also depend on the tax paid by R&D organizations for the use of state resources, and that is not available in advance.

A potentially highly disruptive factor was the conflict between the optional R&D contracts with industrial users and the mandatory orders from the state for R&D projects. The latter tend to interfere with the workload of the R&D institutes and may discourage prospective customers. The GKNT was again on the side of free enterprise, emphasizing that contract agreements extend to the ministries, which must pay for their orders and therefore must be more careful in burdening R&D.

The most disconcerting factor appeared to be the new degree of independence after "years of brutal regulations about any trifle." [77]

REGULATORY MECHANISM

A field report on the implementation of restructuring has been submitted by Aganbegyan, who questioned a group of local managers representing consumer and producer goods industries. The group showed considerable unanimity in noting the following:[78]

- Many aspects of restructuring remain a matter of talk and paper shuffling. The radical changes expected of the restructuring effort have not occurred. For example, the restructuring decree provide that technological modernization is to be carried out with enterprise resources. But the regulations to interpret these decrees have not been formulated, and old regulations still in force prohibit modernization expenditures without

approval of the ministry. The existing, unchanged regulations thus effectively negate the restructuring decrees.

- The local managers emphasized bureaucratic inertia that impedes the restructuring process: top-level decisions are not being implemented at lower levels. Old ministers may be dismissed, but old procedures have not been changed. There are many attempts to demonstrate changes which in reality did not take place.[78]
- The principal point of the criticism concerns the regulatory mechanism. Since the established body of regulations rigidly controls every economic transaction in the USSR, the failure to promulgate timely and appropriate changes throughout that body will inevitably arrest the implementation process regardless of the wishes of the Soviet leadership. Thus, the administrative problem of disseminating updated regulations throughout the country appears as yet another obstacle to restructuring, alongside the resistance of those whose interests are vested in the old order.

THE PROGRESS OF DECENTRALIZATION

Aganbegyan's group had a number of revealing comments on the decentralization objective of restructuring. The participants noted that while the restructuring process has so far been manifested by pressure from top leadership and by increased work discipline, centralized control has actually increased, instead of decreasing. For example, a reporting system introduced two years ago consists of so many questions to be answered by production associations that several dozen clerks are needed. There are now more checkers than production workers.

Perception of excessive control from the top prompted one production association director to say, "I am not a director, not even a smart robot, but a dumb robot programmed by someone higher up; as for myself, I am nobody." [78]

According to Aganbegyan, the new economic approach, introduced at the beginning of 1984 as an experiment in a small group of industrial ministries, was practiced in 1986 by one-half of all industrial enterprises. Although the approach has had some positive results, Aganbegyan does not consider it a radical reform. The independence and rights of enterprises have been somewhat strengthened, but the change is not big enough. Petty control over enterprises and production associations, and the old incentive-inhibiting rules continue as before.

Aganbegyan believes nevertheless that the system has considerable potential for improvement; those individual establishments that were granted greater independence and responsibility for results have experienced a veritable explosion of incentive and activity, increasing productivity by 30 percent in one year.[14]

In his June 1987 report of the Central Committee, Slyun'kov emphasized the need to find an optimal relationship between centralized planning and enterprise autonomy. The enterprise, and not the ministry, will determine and prescribe its entire production program and will operate on the principle of total self-financing and self-support. As a rule, budget financing will be eliminated.[72]

Marchuk reports a similar situation in the Academy of Sciences. The "all-important" decentralization has not been carried out, although autonomy at the departmental level has been somewhat increased. The net effect of the restructuring effort is not more opportunity for individual initiative, but more rigorous planning based on long-range forecasts and tighter control of performance.

The main concern was that decentralization not deprive the Presidium of the Academy of global control of research. Centralized control of many other management functions of the Academy should descend one level—from the Presidium to the departments—while the Presidium should retain coordination of national research.

The Presidium of the Academy will also retain centralized control of resource allocation and will work jointly with Gosplan, the State Committee for Science and Technology, and the Council of Ministers. As Marchuk puts it, centralization is retained at the level of mutual interaction of the Academy with state agencies.[3]

THE PROCESS OF INNOVATION

Soviet analysis of the problems of industrial innovation based on new technology being developed by the Academy of Sciences blames industry more than the Academy for the existing situation. The criticism consistently voices the theme of industrial unwillingness to innovate, a legacy of the extensive development mode discussed above. Also, industrial resistance to the absorption of new technology is attributed to lack of incentives, rather than to technological ignorance.[4] The pervasive lack of industrial interest in new inventions is perceived as the crux of Soviet technological problems: Inventions that increase productivity are seen by the industry as contributing nothing except increased production quotas imposed from above.[34] Therefore, industry is much less concerned with innovation plans than with production plans in industrial enterprises.[46]

The system of industrial R&D, in which several research institutes participate in a project under the technical direction of a so-called leading institute, throws up another obstacle on the path of innovation. The leading institutes tend to assume a jealous hegemony over projects they direct and resist accepting the results of research from organizations outside the industry, such as the Academy of Sciences.[55] The refusal of the Soviet aircraft industry to use composite materials developed by the Academy of Sciences, which claims to have achieved "superb results" in this field, is a good example of this conflict.[8] Another example is Soviet lag in fiber-optics cable communications and television, although the Academy has also made a significant advance in this area. The lag is attributed to the lack of high-quality fiber-optics industrial production technology.[6]

A more specific interpretation holds that industry is willing to receive only those Academy projects that have been brought to completion.[10] Soviet industrial research institutes are found technically unprepared to absorb the results of the Academy's research, even though they receive 90 percent of the science budget, with only 10 percent going to the Academy. Thus, there is no proper coordination between the Academy and industry that would realize the full industrial potential in exploiting advanced technology.[3]

The worst situation is found in plants manufacturing consumer goods which must produce their own technology base without scientific and engineering cadres, even though such technology is being produced elsewhere.[78]

On the other hand, many research projects developed by the Academy are not directly usable by the industry because they lack a stage bridging the Academy output to further technological adaptation.[55] The industry is not assisting the Academy with experimental research technology.[10]

The industrial innovation process is further hampered by the cumbersome regulations binding the Academy of Sciences in its relations with industry. Each transfer of Academy R&D results to industrial production must be approved in a joint session of Gosplan USSR, State Committee for Science and Technology, and the Presidium of the Academy of Sciences, USSR. Approved proposals for such transfers (or innovations) are then taken into account in the preparation of the Five-Year State Plan for the Economic and Social Development of the USSR.[18]

ASSESSMENT OF THE MNTK NETWORK

The basic purposes of the MNTK system have been repeatedly emphasized by Academy leadership: to integrate science and industry,

to concentrate resources in priority areas of science and technology, to surmount bureaucratic obstacles in development and production, and to sweep away departmental barriers which have become notorious. The MNTK principle will finally unite diverse collectives under "one roof" and the unified management plan will help speed up the entire cycle from the basic idea to production of new equipment.[69,79] There is a broad consensus among participants of MNTK reform that these goals are important, urgent, and long overdue. However, there is also nearly as much agreement that the dynamism inherent in the MNTK concept has been altogether absent in practical implementation.

As Yu. A. Ovchinnikov, vice-president of the Academy of Sciences, put it: "There is the paradox: The top [leadership] designates the MNTK as an instrument of acceleration. But then their material resources, their base, are still being realized by traditional, unhurried methods." [80]

All the early responses from the field dealing with the organization and operation of the new MNTKs paint an unsatisfactory and pessimistic picture of MNTK development.

One highly significant response comes from B. Ye. Paton, president of the Ukrainian Academy of Sciences, since he is the originator of the MNTK system. Although the new MNTKs are far from being fully operational, Paton sees them as incorrigibly fragmented and hard-to-manage conglomerates of enterprises and scientific research organizations. The right granted to MNTKs to independent contracting and financing control of R&D projects—as the main lever to force innovation—has not been realized. Neither have the many resolutions to improve the linkage between science and production because of incompetence and frequent unwillingness to use the new laws and opportunities. As a result, Paton says, the MNTKs are already called paper tigers.

Paton attributes many of these problems to what he calls the unjustified and artificial rules, established by Gosstandart SSSR (State Committee for Standards), governing the procedures the MNTKs must follow in guiding their research projects to the production stage. The excessive volume of the required technical documentation and interagency agreements entails a time loss of up to two to three years. He concludes that the attainment of world-level technologies will remain wishful thinking if the present situation is allowed to continue.[67,81,82]

The slow pace of the organization of MNTKs was also criticized by such Academy leaders as first vice-president V. A. Kotel'nikov, vice-president P. N. Fedoseyev, chairman of the Academy's Siberian Department V. A. Koptug, and L. M. Brekhovskikh, secretary of the

Academy's Department of Oceanology, Atmospheric Physics, and Geography.[30,34,68,83]

The main problem at this time appears to be the reluctance of the industrial ministries to cooperate with the Academy's component in the MNTKs and to adapt to more efficient ways of introducing the results of R&D into production within the MNTK system. Clearly, there are no adequate moral and material incentives for the industry to change its old practices.[34,68,69,83]

These complaints indicate that authority has not been centralized within the MNTKs, their ability to manage is poor, and they are left without sanctions and incentives.

In the individual MNTKs, industrial enterprises are unwilling to discontinue a significant portion of their production lines in order to shift production to new MNTK-specified technologies.[84] The ministries fail to provide operational funding to the MNTKs to match the Academy's contributions.[85] The traditional forms of materials and equipment supply are being retained, requiring that resources be ordered years in advance.[79] Finally, the MNTKs must deal with too many ministries and agencies, causing excessive bureaucratic problems.[66]

An illustrative analysis of MNTK problems has been provided by V. S. Golubev, deputy director for research of the Academy's Research Center for Industrial Lasers (NITsTLAN), the head organization of the Industrial Lasers MNTK. Golubev lists the following major causes of the poor performance of the network:[57]

- The ambiguous legal status of the MNTKs that allows the organizational fragmentation of the R&D cycle to continue. The applied research institutes and production associations who are members of the MNTKs continue their administrative subordination to their respective ministries and identify their interests with the latter.
- Lack of unified financial or material resources among the MNTK components, making it difficult to maintain unified wage and incentive standards.
- The fact that the MNTKs are governed by goal-oriented (*tselevyye*) programs which are not included in mandatory state plans. Gosplan and the State Committee for Science and Technology have not yet confirmed plans that would force cooperation among MNTK components. Therefore, no official sanctions can be applied for violations of delivery dates or of contractual obligations by MNTK suppliers.

The immediate objective of the MNTKs is procurement of basic facilities and personnel. Some of these facilities are being obtained from capital investment. For example, the share of capital investment for the pilot plant and technological support base of the Academy of Sciences has almost quadrupled since the 10th Five-Year-Plan, reaching 15 percent in the 12th Five-Year-Plan.[30] Other facilities are to be realized from conversion of existing industrial assets. The conversion process has its own set of pitfalls.

The Industrial Lasers MNTK also provides a comprehensive example of the problems involved in the establishment and early operation of MNTKs and in the conversion process. A commentary on these problems comes from G. A. Abil'sitov, general director of the MNTK, and Golubev, both representing the R&D viewpoint, V. G. Zav'yalov, director of the *Sibelektroterm* Production Association, representing the production viewpoint, and an observer, N. T. Stavrukov of Chuvash State University.

The Industrial Lasers MNTK is under joint jurisdiction of the Academy of Sciences, USSR, and the Ministry of the Electro-technical Industry (*Minelektrotekhprom*). It has been established to develop and produce 1 to 10 kW laser systems for welding pipes and driveshafts; cutting composites, superhard alloys, and ceramics; surface treatment of materials and machine parts; and plasma powder sputtering.

Beside NITsTLAN, whose first stage was put in operation in February 1986, the MNTK is to include a series of organizations designed to achieve a complete sequence of research-to-production stages.[7,57,58,86] Golubev notes that there is a hierarchy among these organizations in the degree of association with the MNTK: organizations belonging to the MNTK are members (*ukhodyashchiye v MNTK*), further away are participants (*prinimayushchiye uchastiye*), and furthest are collaborators (*sotrudnichayushchiye*).[57] It is not clear, however, what limitations, if any, are imposed on the rights and obligations of participants and collaborators, as distinct from members of the MNTK.

Basic research of the Industrial Lasers MNTK is to be performed by six member research institutes, five of the Academy of Sciences, USSR, and one (Institute of Atomic Energy) of the State Committee for Atomic Energy. Applied research is represented by the collaborating Institute of Theoretical and Applied Mechanics of the Siberian Department of the Academy of Sciences. Development is in the hands of two member institutes under the jurisdiction of *Minelektrotekhprom*: the All-Union Research Institute of Electro-thermal Equipment and the All-Union Research Institute of Electric Welding Equipment. The Moscow Electro-thermal Equipment Plant of *Minelektrotekhprom*

(member), is the pilot plant, and the *Sibelektroterm* Production Association (participant), the Tbilisi Electric Welding Plant (member), and the Induktor Plant (participant), all of *Minelektrotekhprom*, will handle mass production.

The two industrial research institutes and the Moscow and Tbilisi production plants have all been engaged in work meeting their current operating plan quotas. According to Abil'siitov, they will have to be released from this commitment and converted to meet the needs of the MNTK.[86] He gives no information as to what organization, if any, would take over their previous research and production responsibilities.

So far, the two industrial institutes of *Minelektrotekhprom* responsible for the design and prototype construction of the laser systems have failed to assign enough resources to the project. As a result, there is a large gap between research and the later stages of the R&D cycle, so that the chain from scientific idea to its realization has not been closed. This, in turn, has led to a disproportion between the scientific and production components of the MNTK. The scientific component is much the stronger of the two and the scientist-leaders of the MNTK are largely ignorant about engineering design work and production.[57]

Minelektrotekhprom has also failed to implement mass production of industrial lasers within the MNTK. This task had been levied on the ministry within the framework of the 11th Five-Year Plan.[57] In discussing this failure, Zav'yalov identified the lack of proper specialization in the production of laser devices as the major bottleneck in the present early stage of operation of the MNTK.[87]

The leading production plant of the *Sibelektroterm* Association has been manufacturing large-size electrothermal equipment measured in tens of meters and weighing hundreds of tons. This is in sharp contrast with laser technology, which requires precise and delicate treatment based on a very different psychology and ideology of production. As a result, the main production shops have been able to participate little in the manufacture of laser systems. Laser development is being performed on a small scale by the same specialists engaged in the main production operations of the Association.

A critical component of laser systems is precision optics. Stavrukov notes that optics represents the greatest stumbling block today in the development of laser technology and that it is impossible under current Soviet conditions to organize the supply of optical devices on a cooperative basis.[9] The optics problem clearly shows the fallacy of imposing the task of manufacturing highly sophisticated precision equipment on generalized production enterprises. Golubev says that optical devices and microprocessor-based controllers for industrial laser tools can be obtained by the MNTK only if it is allowed to build its

own specialized production facilities endowed with proper equipment and expertise. Permission for such facilities has not been granted by *Minelektrotekhprom*. [57]

In addition to facility constraints, there are problems obtaining qualified personnel. There is a shortage of engineers in Siberia, compounded by a rigid limit imposed by the Ministry on the wage fund and its refusal to allocate separate wage funds for the laser work. [87]

Zav'yalov concluded that the establishment of a specialized laser production base in the *Sibelektroterm* Association remains in doubt. Speaking in more general terms, Golubev voiced a similar doubt that the MNTK network will successfully cope with the problems of interagency cooperation and be able to implement its program. [57,87] In the words of Abil'siitov, "MNTKs must be established in a revolutionary, dynamic way. Otherwise all will drown in bureaucratic phraseology, opportunistic adjustments, convenient agreements, etc. Many new endeavors were mired on that road." [86]

VII. THE PROSPECTS FOR SOVIET ADVANCED TECHNOLOGY

Soviet problems with R&D arise to a large degree from the revolutionary nature of advanced technology. Its successful development requires a new economic and industrial environment that is essentially incompatible with rigidly applied principles of planned economy. Technological progress involves risk and uncertainty, and neither can be tolerated within the discipline of carefully designed, all-encompassing plans. This incompatibility has been perhaps the deepest and the most damaging of the many factors that emerge as causes of Soviet technological weakness.

The Soviet system has so far failed to create a favorable environment for technological evolution. Soviet technology encounters obstacles to development in practically all dimensions that matter: economic, organizational, political, social, and even military. The economy has created severe disincentives to industrial innovation. Organizational interagency barriers stand between R&D and production, and particularly, between the Academy of Sciences and the industrial ministry system. The political and social system restricts the free flow of scientific and technical information, skews the distribution of top scientific personnel between R&D and industry, and decreases personnel mobility, hampering effective assembly of interdisciplinary teams. Finally, the risky and bold character of new-in-principle technologies runs counter to the established conservatism and incrementalism of a Soviet defense industry which may also feel threatened by the potential drain of resources away from traditional military procurement goals.

It is the Soviet systemic reaction toward risk and uncertainty in technological innovation that has the greatest negative influence on the development of advanced technologies. In the West, one mechanism that makes innovation possible is represented by risk-taking entrepreneurs who are willing to invest in a new technological idea and carry it through production to the market. Risk-taking and the expected reward for risk are the essential force that drives the proliferation of new technologies and their accumulation into a technology base which, in time, becomes rich enough to provide ready support for unanticipated new technological developments.

But Soviet society is profoundly averse to risk. The technological entrepreneur is the state, primarily the military, which tends to

minimize the risk inherent in all technological development. Hence the Soviet tendency toward incremental and conservative development, and toward emulation of proven Western designs. As a result, Soviet technology is largely pulled by administratively dictated or perceived military requirements, rather than pushed by advancing ideas. One outcome is a nation that is a technological follower, rather than a leader.¹ Another, more significant outcome, is an impoverished technology base in which sophisticated modern technologies exist side-by-side with technological gaps—the missing technologies that must be procured from the West. Many of the currently available Soviet technologies have been initiated by state plans and well-focused resources; on the other hand, many of the technologies missing from the Soviet base have been developed elsewhere by risk-taking entrepreneurs operating outside state planning mechanisms. Technological progress, which cannot be foreseen with any degree of precision, may be found to depend critically on this unplanned, risk-taking element, which so far has been absent from the USSR.

The significance of this element in stimulating technological development has been recognized by Soviet economic reformers who now propose to inject a degree of risk-taking into the R&D process. The new decree of the Soviet government, placing R&D organizations on a self-supporting basis, attempts to cast at least some research institutes in the role of free entrepreneurs of technology. The expectation is that, under liberalized rules governing the distribution of profit-derived revenues, these institutes will be able to launch the development of new technologies because of their inherent potential, rather than in response to state direction.

But the prospective new forces in the Soviet R&D establishment can be unleashed only if the entire range of economic benefits promised by restructuring is realized in practice. A close reading of the several decrees involved and early reports from the field indicate that this is not likely. The regressive tendencies affecting Soviet R&D appear in the conservative bias of the technological priorities and the limits on management autonomy of R&D institutions that participate in production associations and enterprises.

The technological conservatism evident in the restructuring blueprint threatens to defeat the attempt to upgrade the Soviet technology

¹Yefimenko, the GKNT interpreter of R&D reform, is well aware of the danger in the path of a technological follower: "Experience shows that if you see that somebody [abroad] started developing something new in your area of science and technology, you are already three-to-five years behind. The development of science should not be stimulated by items already put on sale or found in foreign publications, but by the results of technological forecasting." [11] Here, Yefimenko still sees centralized forecasting, rather than risk-taking entrepreneurial initiative, as the basis of technological leadership.

base. The "Main Directions" Program fails not only to give full play to the development of advanced technologies, but also omits any reference to the major enterprise of the Academy of Sciences in rescuing computer technology. This lack of top-level support of a vitally needed technology casts a doubt on the ability of the restructuring drive to reform any Soviet institution dedicated to advanced technology.

The apparent reluctance to proceed vigorously with the development of computer technology may have far deeper roots than missed technological opportunities and bureaucratic infighting. Today's world revolution in technology is, first of all, a revolution in the technology of information and communications. This is the meaning of the word "Informatics" in the name of the principal new institute of the Academy of Sciences dedicated to computer development. But an uninhibited development of computer-based information and communication networks directly threatens the long-standing Soviet policy restricting the free flow of information throughout Soviet society.

A full license for risk-taking entrepreneurship and unimpeded flow of information both run counter to the established tenets of the Soviet political system. In this view, therefore, Soviet failure to keep pace with the West in technological development is ultimately political in origin and can hardly be reversed without profound political changes of the system.

Again, the significance of the information issue has been appreciated by Soviet leadership in its stress on *glasnost*, or openness in social, political, and economic affairs. In view of the foregoing discussion, *glasnost* emerges as a reform measure that is critical to the success of advanced technology development.

Another important obstacle to restructuring is the disparity between the new top-level policies formulated within the restructuring framework and the manner of their practical implementation across the middle and lower levels of Soviet bureaucracy. This issue has been perceived by nearly all Soviet observers and has been acknowledged by the Central Committee, which noted the slow and uncertain implementation of its directives.

Implementation delays may not necessarily be only a matter of bureaucratic resistance to change and protection of old vested interests. In a large measure, they may also be due to the nature of the Soviet system manifested in a body of pervasive regulations that control all economic activities. Since restructuring did not abolish the principle of regulation, the regulatory code remains and must be amended by official changes introduced at all administrative levels. A comprehensive amendment of regulations is a vast enterprise in its own right, and should provide many opportunities for obstructing progress of the reforms.

The faltering manner in which the reforms are being implemented in practice threatens the viability of its most effective component—the new economic incentives. These must be installed and enforced well before the expected effects of restructuring begin to be felt. Particularly significant are the measures requiring a contractual agreement for every research task, competitive bidding for industrial contracts, and above all, placing profits and hard currency at the disposal of R&D organizations.

But the autonomy of some R&D organizations is limited by parent associations who control their profit and income. As a result, the production quotas imposed on the associations and enterprises will continue to influence R&D. Since the decree on self-support requires association membership of all industrial R&D organizations, only relatively few types of Soviet R&D organizations may be in a position to engage in independent technology development ventures.

At this time, none of the reform measures seems to be well established, and what is equally important, well understood by Soviet science and industry managers. The confusion about their precise meaning is compounded by the absence of an economic theory of restructuring; as an interesting comment on this situation, some members of the Academy of Sciences have volunteered to develop such a theory.

The lack of a theoretical underpinning of radical economic reforms is ironic in a society dedicated to theoretical formalism and guidance in all its activities, and demonstrates the urgency of the task of changing the existing economic relations. Nevertheless, it may be found profoundly disconcerting to people conditioned by permanent obeisance to ideology. The urgency to reform also threatens to push radicalism beyond the limits of what Soviet society can tolerate: wages adjusted according to quantity and quality of output may generate powerful opposition to restructuring on the part of labor.

Indeed, the problem of labor relations appears to be the only real target of the radicalism evident in restructuring. As noted above, radicalism has been manifested neither in the vigor of implementing reform, nor in the promotion of advanced technologies. This is in accord with popular accounts of restructuring in the Soviet press, which tend to show that real progress has so far been made mostly in combating absenteeism and alcoholism in the working population.

Nevertheless, it is imperative for the Soviets to make restructuring work both to bolster the economy's capability to respond to growing societal demands and to secure military capability to compete in terms of advanced technologies.

The restructuring drive appears to be primarily directed at the civil sector of Soviet economy, where its immediate aim is to reverse the downward trend of industrial productivity. The lagging Soviet civilian

economy has a greater need of improvement than the military sector which, at least in the traditional technologies, has been operating at adequate levels. The development of advanced technologies, however, has a potential impact on both sectors.

Soviet military planners were heretofore able to develop effective traditional weapon technologies by concentrating resources on relatively narrow segments of the science and technology spectrum. The necessary R&D projects could then be planned according to an orderly, predictable, long-term schedule. But the advent of advanced technologies in military affairs and the faster pace of technological innovation have made such an approach no longer tenable. Future weapons design will require broad-spectrum interdisciplinary R&D efforts and the ready availability of a broad base of advanced technologies. The latter come from the civil sector which, as a massive random generator of technologies, has now acquired a profound military significance. The Soviet Union does not have such a base today; neither does it have a mechanism for vigorous development of technologies outside the predictable and currently recognized needs of the state. Although the military has been using forecasts by leading scientists in the selection of investment targets, this is not a sound investment policy since technological progress is essentially not predictable.

Insufficient advanced technology capability poses a serious threat to the Soviet military and economic posture. The threat is especially clear in connection with the Strategic Defense Initiative of the United States, which depends entirely on highly developed advanced technologies. The SDI threat is not necessarily directly related to the question of the feasibility or practicality of the underlying concepts; rather, it is a threat of competition along a new technological frontier. Therefore, a part of the impetus behind Soviet restructuring could perhaps be attributed to the launching of SDI in 1983 and the ensuing prospect for high-technology competition.

Soviet ability to meet that competition seems to depend heavily on the success of those R&D organizations, operating under the Academy of Sciences and directly under the industrial ministries, that are now free to control their own profits and budgets and to pursue independent ventures in technological development. The actual share of such organizations in the total Soviet R&D potential is unclear. It is even less clear where these organizations will find the sponsors willing to pay for R&D ventures not included in state plans. Soviet industrial enterprises capable of transforming R&D results into useful products are constrained by the planning system and are not likely to be receptive to such ventures. To realize its goals, restructuring must extend the freedom of independent technological development all the way to the production end of the R&D cycle.

The extent of this freedom, in turn, depends on how far current reformers are prepared to go in changing the Soviet economic system. The recent experience in implementing reform does not indicate significant departures from past practices. In addition to the lack of a solid theoretical foundation for the reform, the official decrees promulgating the reform measures give the impression of chaotic, hastily drawn documents more intent on the nominal installation of restructuring in Soviet society than on a thoughtful analysis of the problems and the necessary remedies for Soviet R&D and industry.

From a broad theoretical viewpoint, Soviet technological problems can be traced to the idiosyncratic Soviet approach to economic modeling. Whereas Western economists use models to analyze the economy, Marxist economic models have been used to synthesize Soviet economy. Since models typically provide a simplified and incomplete representation of reality, the synthetic framework superimposed on Soviet economic life necessarily fails to account properly for many of the more complex economic relationships. The price of this failure is exacted with particular vengeance on the economics of technology, in which the Marxist model lacks the power to harness the unpredictable nature of technological progress.

Appendix A

THE ORGANIZATION OF THE ACADEMY OF SCIENCES IN THE COMPUTER FIELD

The Department of Informatics, Computer Technology, and Automation was established at the 1983 General Meeting of the Academy of Sciences.[39]

The Presidium of the Academy of Sciences, USSR, has subordinated 12 research institutions to the new Department. Of these, four represent newly created institutes, seven are institutions transferred from other departments of the Academy of Sciences, USSR, and one has been transferred from Gosstandart, USSR. Table A.1 shows the institutions under the jurisdiction of the new Department, the cases of shared jurisdiction, and their former affiliations.

These changes amounted to considerable losses for the Department of Mathematics and the Department of Mechanics and Control Processes, which were deprived of major computing centers and research institutes, and to shifts in jurisdiction for the Departments of General Physics and Astronomy, Physical Chemistry and Inorganic Materials Technology, Biochemistry, Biophysics, and Chemistry of Physiologically Active Compounds, and Physical Chemistry and Inorganic Materials Technology, which now share supervision with the Department of Informatics, Computer Technology, and Automation over several of its newly acquired institutions.

The individual research institutes of the Academy were not affected by the reorganization. The institutes and computing centers of the new Department were transferred intact, retaining their former directors and deputy directors, with a few new deputy directors added after the transfer. An exception was the Institute of Problems of Microelectronics Technology and High-Purity Materials, created out of a part of the Moscow Institute of Solid-State Physics, whose deputy director, Ch. V. Kopetskiy, and senior researcher, V. V. Aristov, became director and deputy director, respectively, of the new institute.

It would appear that the computer technology reorganization has been confined to the USSR Academy of Sciences only and did not affect its Siberian Department or the republican academies. A significant indication of this is the fact that the Computer Center in Novosibirsk and the important Glushkov Institute of Cybernetics of the Ukrainian Academy of Sciences have not been affected admin-

Table A.1

INSTITUTIONS SUBORDINATE TO THE DEPARTMENT OF INFORMATICS,
COMPUTER TECHNOLOGY, AND AUTOMATION [88]

Institution	Jurisdiction Shared with	Former Jurisdiction
Moscow Computing Center		Department of Mathematics
Keldysh Institute of Applied Mathematics		Department of Mathematics
Institute of Informatics Problems		New institution
Institute of Cybernetics Problems		New institution
Institute of Problems of Microelectronics Technol- ogy and High-Purity Materials	Department of Physical Chemistry and Inorganic Materials Technology	New institution
Institute of Micro- electronics	Department of General Physics and Astronomy	New institution
Institute of Computing Technology Problems		Unknown
Institute of Information Transmission Problems		Department of Mechanics and Control Processes
Leningrad Scientific Research Computing Center		Department of Mechanics and Control Processes
Pushchino Scientific Research Computing Center	Department of Biochemistry, Biophysics, and Chemistry of Physiologically Active Compounds	Unknown
Commission for Computing Technology		Unknown
All-Union Scientific Research Center for the Study of Surface and Vacuum Properties	Department of Physical Chemistry and Inorganic Materials Technology	Gosstandart, USSR

istratively. The case of the Glushkov Institute is particularly striking, because it is a key research facility in the computer field and it should be expected to play a leading role in any major developments in that field.

According to Velikhov, the research base of the new Department consists of two existing and four new institutes. The two existing institutions are the Moscow Computing Center of the Academy of Sciences and the Keldysh Institute of Applied Mathematics, which have traditionally led the development of computer technology and accumulated considerable experience in solving major problems.[39] However, it is the four new institutes that have, so far, defined the key R&D objectives of the new Department, including small computers for mass use, large supercomputers, and advanced microelectronics materials, devices, and their fabrication methods.

The missions of the four new institutes are outlined below.

Institute of Informatics Problems (*Institut problem informatiki*)

B. N. Naumov, director; V. G. Zakharov, deputy director.[38,43]

The primary mission is the development of small, high-capacity computers for mass use. Intended for scientific research, automation and design work, and use in flexible automated production lines, their equivalents in the West are the VAX, MV-10000, and IBM-4300. Another objective of the Institute is the development of microcomputers and small computer systems. Together with the Computing Center of the Academy of Sciences, the Institute is charged with overcoming a major deficiency of computer technology in the USSR—the lack of personal computers. This calls for the development of a universal mass-use machine on a scale sufficient to reach the Soviet equivalent of Western production levels of 4 million units per year, and the corresponding software for users not familiar with programming.[39]

An interbranch scientific-technical complex, "Personal EVM," is being organized. The complex is expected to function according to a unified strategy of design, production, and mass dissemination of computers.[38]

Institute of Cybernetics Problems (*Institut problem kibernetiki*)

V. A. Mel'nikov, director.[43]

The primary mission of the institute is the development of supercomputers capable of performing over 1 billion operations per second,

including the development of a system of automatic design of super VLSI, multilayer printed circuits, and supercomputer architecture.[35]

The institute will design supercomputer architecture jointly with the Siberian Regional Center, the Glushkov Institute of Cybernetics of the Ukrainian Academy of Sciences, and the *Minelektronprom* and *Minradioprom* ministries. Supercomputer software will be developed by the same joint effort at the branch of the Institute of Cybernetics Problems being established in Pereslavl-Zalesskiy.[39]

The first-generation model of the supercomputer is expected to reach 300 million scalar and 150 million vector operations per second. The machine will require the development of totally new types of VLSI and a new overall design to deal with the large amount of generated heat. The supercomputer is intended for use in automated design and the development of systems larger than VLSI.[39]

Institute of Problems of Microelectronics Technology and High-Purity Materials (*Institut problem tekhnologii mikroelektroniki i osobochistykh materialov*)

Ch. V. Kopetskiy, director; V. V. Aristov, deputy director.[39,43]

The Institute has been based around a large scientific team acquired from the Institute of Solid-State Physics and has been provided with a Special Design and Technology Bureau and a pilot plant.[39,44]

Current projects of the Institute include the following:[39]

Miniature capillary X-ray source, developed jointly with the Ministry of Electronic Industry.

Submicron optical and ion lithography, developed jointly with the Institute of General Physics, the Institute of Radioengineering and Electronics, FIAN, and the Institute of Nuclear Research.

An instrument for the study of surface structures in diverging X-rays, scheduled for production by the Academy of Sciences.

Magnetic 600-megabyte storage disks, developed jointly with industry. Kopetskiy is leading the work on vertical magnetic recording, expected to increase disk density by an order of magnitude.[39]

Institute of Microelectronics (*Institut mikroelektroniki*)

K. A. Valiyev, director.[43]

Some projects of the Institute of Microelectronics are shared with those entrusted to the preceding institute. The institute has a design bureau in Yaroslavl.

In the agendas of the new institutes, one can discern three basic aims of the new Department: (1) to catch up with the Western proliferation of mass-use small computers, (2) to maintain a position at the leading edge of research in supercomputer R&D, and (3) to provide the necessary materials and techniques for the first two aims.

The reorganization of the Academy of Sciences in the computer field was not confined to the establishment of the new Department, but also involved setting up an extensive network of projects to be pursued jointly by the institutions of the new Department and other Departments of the Academy, the industrial ministries, and universities.

Among the projects of the Department of Informatics, Computer Technology, and Automation, the development of supercomputers appears to involve the most extensive interaction with industry. The design of supercomputer architecture and software in the Institute of Cybernetics Problems extends beyond the Department to the Glushkov Institute of Cybernetics, the new regional center of computing technology in the Siberian Department, and the enterprises of the ministries of Electronics Industry and Radio Industry.

On the other hand, the development of small computers entrusted to the Institute of Informatics Problems appears, at this stage at least, to be confined entirely to the new Department of the Academy and no direct industrial linkages have been specified by Velikhov.

The advanced materials and fabrication technique projects of the two new microelectronics institutes extend to a block of Academy institutes outside the new Department, but beyond the Academy involves only the Ministry of Electronics industry. The block of Academy institutes, assembled for the purpose of developing a new generation of microelectronic devices based on new physical effects and new technology, consists of the Leningrad Physico-technical Institute, the Institute of Radioengineering and Electronics, the Institute of General Physics, the Lebedev Physics Institute, and the Institute of Crystallography.[39]

The development of advanced lithographic techniques appears to involve the largest number of participating institutions, including the Institute of Nuclear Research in Novosibirsk, which has three electron storage rings as synchrotron radiation sources that in the X-ray range have lithographic applications. The Institute is now operating a complete production line for X-ray lithography and, together with enterprises of the Ministry of Electronic Industry, it is developing the technology for mass-producing microelectronic circuits with submicron elements. The next objective is to reproduce masks, and the main mission is the development of ultra-large and ultra-fast VLSI with submicron elements.[51]

Another major project of the Institute of Problems of Microelectronics Technology is the development of 600-megabyte magnetic storage

disks, of special importance to the Institute director, Ch. V. Kopetskiy, who leads the work on vertical magnetic recording, which should increase disk density by an order of magnitude.[39]

A commission has been set up to coordinate the joint action of the new Department with the other institutes of the Academy and industry.[39]

The Moscow Computing Center is cooperating with the Institute of Informatics Problems and with the ministries of Communications Equipment Industry and Electrotechnical Industry in establishing uniform standards for personal computers. At this time, standards for two computer types are being worked out. The first is intended for schools and universities to eliminate "computer illiteracy." The second is intended for scientific research institutions and industrial design bureaus.[39]

The Moscow Computing Center also serves as a research base for the Scientific Council on the Complex Problem of Cybernetics,¹ which has set up three new research centers, one of which works with the above ministries.

The first center is intended to support theoretical physicists and has established a cooperative linkage with the Landau Institute of Theoretical Physics. The second center is dedicated to the development of an automated VLSI design system in cooperation with the Ministry of Communications Equipment Industry and the Ministry of Electrotechnical Industry. Its mission is to develop an automated system of VLSI design in cooperation with the appropriate institutes. The VLSI will be based on 16- and 32-bit microprocessors required for the next generation of computers. This mission is also assigned to all microelectronics research projects in the Academy of Sciences. The third center consists of Moscow State University and the Likhachev Automobile Plant and deals with automation of machine design.[39]

In 1984, the Academy of Sciences was charged with formulating a national program for the development of microelectronics and computer technology up to 1990. The key areas of development were determined and emphasis was placed on the standardization of computer technology.[89,90] However, it was not clear what should be the overall level of effort implied in the national program. For example, in 1985 Yershov argued that computerization should be elevated to a superproject status, coordinated at the Politburo level, and the computer industry should be restructured.[45]

¹The newly reorganized Council on the Complex Problem of Cybernetics was elevated to the rank of a scientific research institute. The Council is chaired by O. M. Belotserkovskiy, deputy director of the Moscow Computing Center, and is under the general management of Velikhov, who was nominated to this position by the Presidium of the Academy in 1984.[88]

A separate group of Academy institutes is scheduled to develop a new generation of microelectronic devices based on new physical effects and new technology.[39] The group consists of the Leningrad Physico-technical Institute, Institute of Radioengineering and Electronics, Institute of General Physics, Lebedev Physics Institute, and Institute of Crystallography. The group also includes the Institute of Problems of Microelectronics Technology and High-Purity Materials and the Institute of Microelectronics, which are components of the new department.

Although not subordinated to the new department of the Academy, this group is expected to work closely with it, and a commission has been set up to coordinate the work.

A regional center of computing technology is being organized in the Siberian Department of the Academy of Sciences, USSR, as a separate measure.[39]

At this time, efforts to facilitate the transition of Academy research results to industrial production have taken the form of science-production associations, interbranch science and technology complexes, and temporary technological laboratories established in some Academy institutes. The recently created State Committee on Computer Technology may serve the same purpose on the administrative level.²

²The All-Union State Committee on Computer Technology and Informatics of the USSR was established by the Presidium of the Supreme Soviet of the USSR in March 1986.[91] In April, the Presidium appointed N. V. Gorshkov Chairman of the State Committee. Gorshkov had served in the management of the Ministry of Radio Industry since 1964, and had been Deputy Minister of the Radio Industry since 1974.[92] While his appointment to the chairmanship of the State Committee may reflect at least a nominal industrial control of this coordinating body, it may also indicate a desire on the part of Soviet leadership to make the industry more amenable to cooperation with the Academy.

Appendix B

LIST OF REPORTED MNTKS

COMPUTERS AND AUTOMATION

MNTK: *Personal'nyye EVM* (Personal Computers)

Head organization: Institute of Informatics Problems

Jurisdiction: Academy of Sciences, USSR

General director: B. N. Naumov

Makeup: Scientific research institutions, design and engineering organizations, and testing enterprises.[83]

Mission: To develop and produce personal computers.

Serious problems: No R&D and experimental production facilities; funding provided only by the Academy, none by industrial ministries; excessive bureaucracy—dealing with 34 ministries in pursuit of its mission, four ministries in computer development, and 30 ministries in manufacturing parts and materials; confusion of brands and software.[66]

MNTK: *Robot* (Automated Control Systems).[66]

No data.

MNTK: *Automatika* (Computer-aided Automation).[66]

No data.

ELECTRON-OPTICS AND SCIENTIFIC INSTRUMENTS

MNTK: *Tekhnologicheskiye lazery* (Industrial Lasers)

Head organization: Scientific Research Center for Industrial Lasers

Jurisdiction: Academy of Sciences, USSR, and USSR Ministry of Electrical Equipment Industry

General director: G. A. Abil'sitov[66]

Makeup: Four scientific research institutes, four production plants, design and engineering organizations, and testing enterprises.[58] To include two leading institutes of the Ministry of Electrical Equipment Industry: the All-Union Research Institute of Electro-thermal Equipment and the All-Union Research Institute of Electric Welding Equipment, which will be converted to conform with the MNTK profile. The Moscow Electro-thermal Equipment Plant will be the pilot plant of the MNTK. The plant will be released from its current production tasks and converted to meet the needs of the MNTK. Mass production will be handled by the Electric Welding Plant in Tbilisi, which will also have to be converted.[86]

Serious problems: Lacks key components to span the entire R&D cycle from basic research to production, such as an industrial research institute to develop technological support and a design bureau.[86]

MNTK: *Svetovod* (Light Conduit)

Head organization: Institute of Radioengineering and Electronics

Jurisdiction: Academy of Sciences, USSR

Makeup: Scientific research institutions, design and engineering organizations, and testing enterprises.[83]

MNTK: *Mikrofotoelektronika* (Miniaturized Electron-optics Sensors).[66]

No data.

MNTK: *Nauchnyye pribory* (Scientific Instruments)

Head organization: Leningrad Scientific-Technical Association

Jurisdiction: Academy of Sciences, USSR

General director: M. L. Aleksandrov

Makeup: A number of plants (Orel plant of *Minpribor*), design bureaus, and research institutes.

Mission: Expected to produce one-third of all the precision instruments for science required by the USSR by 1990.

Serious problems: Reluctance of *Minpribor* to drop a significant portion of mass-produced items in its plants working for the MNTK that are not in keeping with MNTK specialization; retention of the traditional forms of materials and equipment supply, which require ordering resources two years in advance.[79]

MNTK: *Radiatsiya* (Radiation).[66]

No data.

METALLURGY

MNTK: *Institut elektrosvarki im. Ye. O. Paton* (Paton Institute of Electric Welding)

Head organization: Paton Institute of Electric Welding

Jurisdiction: Academy of Sciences, Ukrainian SSR

General director: B. Ye. Paton

Makeup: Design bureaus, experimental plant, pilot plants for welding equipment and electrical metallurgy, and enterprises of five all-union ministries.[58,70]

MNTK: *Metallurgmash* (Metallurgy Machinery)

Head organization: All-Union Scientific Research, Planning, and Design Institute of Metallurgical Machines

Jurisdiction: Ministry of Heavy and Transport Machine Building

Mission: Combined solution of scientific and technical problems in the development, manufacture, and industrial introduction of new machines and devices for steel making, pipe rolling, and stamping, based on new advanced technological processes.[58]

MNTK: *Poroshkovaya metallurgiya* (Powder Metallurgy)

Head organization: Institute of Problems of Materials Science

Jurisdiction: Academy of Sciences, Ukrainian SSR

General director: V. I. Trefilov.[93]

MACHINE BUILDING

MNTK: *Rotor* (Automated Conveyor Lines)

Head organization: Design Bureau for Automated Lines (KBAL)

Jurisdiction: Probably industry

General director: L. N. Koshkin

Makeup: Twenty-nine participating organizations belonging to 22 ministries.[69]

Mission: To develop and introduce rotor conveyor lines in industry. Rotor conveyor lines are a new class of machinery that conveys together the machined objects and machining tools. They are being introduced at plants of the chemical, electrical equipment, automotive, radio, and other industries.[94]

Serious problems: Failure to create a system of morale and material incentives for the workers, inadequate scope of operations, unduly long organizational period, mediocre quality.[69]

MNTK: *Mekhanobr* (Advanced Crushing and Pulverizing)

Head organization: All-Union Scientific Research and Design Institute for Mechanical Processing of Minerals

Jurisdiction: Ministry of Nonferrous Metallurgy

General director: V. I. Revnitssev

Makeup: Ten industrial branch scientific research institutes, 10 Academy and VUZ institutes, and industrial combines *Uralmash*, *Novokramatorskiy Mashinostroitel'nyy Zavod*, and production associations.[66]

Mission: To coordinate nationwide processing of raw materials, establish regional scientific and technical equipment and training centers, develop a new generation of crushing and pulverizing equipment to ensure more selective breaking of ores and materials, significantly reduce metal and electric power consumption, and reduce capital expenditures on ore preparation.[66,58]

MNTK: *Impul'snyye mashiny* (Pulsed Machines).[66]

No data.

MNTK: *Nadezhnost' mashin* (Machine Reliability)

Head organization: Blagonravov Institute of Machine Science

Jurisdiction: Academy of Sciences, USSR

General director: K. V. Frolov

Makeup: The Institute of Superplasticity of Metals and the Control Design Bureau of Unique Instrument Building, the *Spektr*, *Burevestnik*, and *Tochmashpribor* NPOs, the Central Steam Boiler and Turbine Institute, and the *Vibropribor* and *Tenzopribor* plants.[67] The Blagonravov Institute, the head MNTK organization, was once transferred from the Academy to industry, and has now been brought back to Academy jurisdiction.[95]

Mission: To develop diagnostic systems, test stands, equipment, and sensors to increase the reliability and service life of machines and components, as well as to reduce substantially machine metal content.[58]

Serious problems: The plants are unable to implement production plans until Gosplan frees them from previous tasks and provides them with production facilities. Developed by the Academy of Sciences and GKNT, the charter of the MNTK has not yet been approved.[67]

CHEMICAL INDUSTRY

MNTK: *Katalizator* (Catalyst)

Head organization: Institute of Catalysis, Siberian Department

Jurisdiction: Academy of Sciences, USSR

General director: K. I. Khamareyev

Makeup: Fourteen research institutes and enterprises of six ministries and agencies. Its national importance is indicated by the fact that 80 percent of new catalysts scheduled for development in the 12th Five-Year Plan by the ministries of chemical, petrochemical, and fertilizer industries will be produced by the MNTK.[68]

Mission: To develop effective catalysts and fundamentally new catalytic processes to increase the economic effectiveness of energy resources and to reduce production cost of chemical products.[58]

Serious problems: The organization of this MNTK is far from completed. After completion, it should be allowed to work for two to three years before its usefulness can be evaluated and measures for further improvement can be formulated.[68]

MNTK: *Antikor* (Anticorrosion)

Head organization: All-Union Inter-branch Scientific Research Institute for Protection of Metals Against Corrosion

Jurisdiction: State Committee of Science and Technology

Mission: To develop fundamentally new types of equipment and technologies that ensure high corrosion resistance, wear resistance, strength of materials and parts, and reliability and durability of machines and structures.[58]

Serious problems: Failure to include such prominent corrosion research organizations as the Institute of Physical Chemistry of the Academy of Sciences, USSR, and the Karpov Physico-chemical Institute of the Ministry of the Chemical Industry.[85]

MNTK: *Termosintez* (Thermosynthesis)

Head organization: Institute of Chemical Physics

Jurisdiction: Academy of Sciences, USSR

Makeup: Scientific research institutions, design and engineering organizations, and testing enterprises.[83]

MNTK: *Membrany* (Membrane Technology)

Head organization: *Polimersintez* NPO and All-Union Scientific Research Institute of Synthetic Resins.[58]

Jurisdiction: Ministry of Chemical Industry [58]

General director: Yu. V. Dubyaga

Will include scientific institutes, a design bureau, experimental bases, and problem-solving laboratories of *Minkhimmash*, *Minlegprom*, and *Minvuz*.

Mission: To develop highly selective membranes for separating gaseous and liquid media, high-performance reverse osmotic, ultrafiltration, and electrodialysis automated separators for extensive use in the national economy. Intended for mass production.[58]

Serious problems: Unified research plan established late; production facilities and scientific training center not yet installed. [66].

PETROLEUM INDUSTRY

MNTK: *Nefteotdacha* (Oil Extraction)

Head organization: All-Union Scientific Research Institute of Petroleum and Gas

Jurisdiction: Ministry of Petroleum Industry

Mission: To develop advanced systems for the extraction of petroleum deposits, and effective technologies and equipment to stimulate productive beds aimed at complete recovery of oil and gas from deep wells.[58]

Serious problems: The Institute of Physical Chemistry refused to participate in this MNTK. While the institute has no specialists in oil prospecting or in petroleum chemistry, it has been included in the plans of the complex, whose management imposes stringent demands on the performance of the institute.[85]

BIOTECHNOLOGY AND MEDICINE

MNTK: *Biogen*

Head organization: Shemyakin Institute of Bio-organic Chemistry

Jurisdiction: Academy of Sciences, USSR

Makeup:

Special Design Bureau of Biological Instrument Making, Pushchino; Bislar NPO, Olayne, Latvian SSR; Institute of Molecular Biology, Moscow; Institute of Biochemistry and Physiology of Microorganisms, Pushchino; Institute of Plant Physiology, Moscow; Institute of General Genetics, Moscow; Main Botanical Garden, Moscow; Institute of Chemistry of Bashkir Affiliate with Experimental Base, Ufa; and Institute of Biology of Bashkir Affiliate, Ufa.

Mission: To use genetic and cellular engineering techniques to develop new types of biologically active substances and compounds for early diagnosis and treatment of diseases in medicine, veterinary medicine, and horticulture.[58]

MNTK: *Latbiotekh* (Latvian Biotechnology)

Lead organization: Kirkhenshteyn Institute of Microbiology

Jurisdiction: Academy of Sciences, Latvian SSR

Makeup: Twenty-two organizations.

Mission: To coordinate the implementation of the *Biotekhnologiya* republican scientific and technical program, which is aimed at developing new biotechnology processes and equipment, various medicinal preparations, genetic engineering, environmental protection methods, and biological sources of energy.

Serious problems: Delayed charter ratification, lack of own wage fund, and lack of money and materials for the construction of experimental and engineering facilities.[84]

MNTK: *Mikrokhirurgiya glaza* (Eye Microsurgery)

Head organization: Moscow Scientific Research Institute of Eye Microsurgery

Jurisdiction: RSFSR Ministry of Health

General director: S. N. Fedorov

Makeup: Experimental plants and 12 branches throughout the USSR.

Mission: Computer-controlled assembly-line surgery with each phase monitored by a color videocamera attached to a voice-controlled microscope. Expected to perform 1000 operations per day, 200,000 per year. To be operational in three years. Will be given authority to solve any problem in any ministry or institution under its supervision, and to place orders abroad for instruments, lenses, and equipment without a middleman. A new system of financing permits it to cover expenses in research and medical treatment as it sees fit.[59]

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